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Présentée par **Kinfe Asayehegn GEBREEYESUS**

IMPACT OF CLIMATE CHANGE ON THE AGRO-ECOLOGICAL INNOVATION OF COFFEE AGROFORESTRY SYSTEMS IN CENTRAL KENYA

Soutenue le 28 Avril / 2017 devant le jury composé de

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Kinfe Asayehegn GEBREEYESUS

Pour l'obtention du diplôme de Docteur en économie

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28 April, 2017

DECLARATION

I Kinfe Asayehegn GEBREEYESUS, declare that this Thesis and the work presented in it are my own and have been generated by me as the result of my own original research.

The work was done under the guidance of Ludovic Temple (HDR), CIRAD, UMR Innovation and Ana Iglesias (Professor), University Polytechnic Madrid (UPM)

Kinfe Asayehegn GEBREEYESUS

April, 2017

Dedicated to my **FATHER** who taught me how life has to be based on knowledge, and what commitment deserves for career development.

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Kinfe Asayehegn Gebreeyesus, Montpellier, 2017

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ABSTRACT

Climate change and variability is the most widespread anthropogenic challenge affecting agricultural production and productivity particularly in the tropics. Coffee sector is sensitive to climate change as it requires relatively cold temperature and higher rainfall duration. Adaptation to climate change in the coffee agroforestry is, therefore, important to address the impacts, but there are barriers, and limits. The aim of this Thesis was to analyze the adaptation strategies to climate change in Central Kenya. We studied the steps in adaptation, which includes (1) the knowledge on climate change and adaptation, the motivation towards adaptation, (2) current choices of households' adaptation strategies, and their determinants, (3) the roles of innovation system and institutional context to support adaptation. This study was based on four sources of information: - (1) Focus Group Discussions to predefine the questionnaires, (2) household surveys, (3) stakeholders interview, and, (4) historical climate data. The data collection considered four farming typologies; - food crops, specialized coffee, diversified coffee-dairy and specialized dairy farming systems in the coffee and food crops zones. Mann-Kendal trend analysis and Sen's slope estimator were used to compare the farmers' knowledge of climate change with the historical climate data, while Heckman model was used to analyze adaptation strategies and their determinants. The findings explore consistent results between farmers' knowledge and historical data analysis for temperature, while inconsistency is observed in rainfall change. Analysis of farmers' perception revealed rainfall is radically declining over time, while no evidence in rainfall record is found to support the farmers' perception. The inconsistency is therefore, substantiated with analysis of patterns. Coffee and food crop farmers are found to adapt to climate change differently. Farmers who are aware of the changes are found more willing to explore adaptation strategies although some of the farmers who do not perceive the climate is changing are also adopting strategies for factors other than perception. The comparison between coffee and dairy sectors found that actors in the coffee are limited, the system is highly centralized with limited options for farmers to process and market their products, while the dairy sector is informally controlled by demand based business and comparatively, numerous actors. We conclude in this study that the patterns in rainfall affects the farming activities of the study area higher than the annual changes. Consequently, farmers adopt a series of adaptation strategies in response to their perception of changes in climate and economic pressure in the farm. This adaptation to climate change also depends on the nature of actors' interaction and institutional context. In relation to policy development, this Thesis contributes to household level adaptation policies, research policies and international agreements and negotiations. The household level policy recommendations consists of three scenarios. Farmers' intensification in coffee applying the right technological innovations. The second and third policy options are the diversification to dairy and complete sectoral transformation to dairy depending on the profitability and adaptation level of the sectors. The results in this study are derived from surveys and analysis of innovation systems. Other strategies such as new infrastructural development and institutional subsidies could be potential for adaptation. We therefore, recommend, these could be potential future research topics.

Keywords: Climate change; Agroforestry system; Intensification; coffee system; Innovation system

RESUME

Le changement climatique et la variabilité ont des répercussions graves dans le secteur agricole des régions tropicales. Le secteur du café est sensible au changement climatique car il nécessite une température relativement froide et une plus grande durée des pluies. L'adaptation au changement climatique dans l'agroforesterie du café est donc importante pour traiter les impacts, mais il existe des obstacles et des limites. Le but de cette thèse était d'analyser les stratégies d'adaptation au changement climatique au centre du Kenya. Nous avons étudié différentes étapes de l'adaptation qui incluent (1) les connaissances sur le changement climatique et l'adaptation, la motivation à l'adaptation, (2) le choix actuel des stratégies d'adaptation et leurs déterminants, (3) les rôles du système d'innovation et du contexte institutionnel. Cette étude repose sur quatre sources d'information: - (1) groupes de discussion sur des questionnaires pré-définis, (2) enquêtes auprès des ménages, (3) entrevues auprès des intervenants et (4) données climatiques historiques sur le contexte de quatre types de systèmes de productions dans l'agriculture : les cultures vivrières, le café spécialisé, les systèmes diversifiés café-laiterie et les systèmes laitiers spécialisés, dans les zones caféières et vivrières. L'analyse des tendances de Mann-Kendal et l'estimateur de la pente de Sen ont été utilisées pour comparer les connaissances des agriculteurs sur les changements climatiques et l'historique des données climatiques, tandis que le modèle de Heckman a été utilisé pour analyser les stratégies d'adaptation et leurs déterminants. Les résultats soulignent des cohérences entre les connaissances des agriculteurs et l'analyse historique des données pour la température mais des incohérences avec le changement des précipitations. L'analyse de la perception par les agriculteurs révèle que les précipitations diminuent radicalement au fil du temps, alors qu'aucun élément de preuve concernant les précipitations ne permet d'appuyer la perception des agriculteurs. L'incohérence est donc corroborée par l'analyse des modèles. Les agriculteurs du secteur du café et des cultures vivrières se sont adaptés différemment aux changements climatiques. Les agriculteurs qui sont conscients des changements sont plus disposés à explorer les stratégies d'adaptation. Une partie des agriculteurs qui ne perçoivent pas le changement climatique adoptent des stratégies d'adaptation à des facteurs autres. L'adaptation au changement climatique est également déterminée par la performance institutionnelle et les différences de systèmes sectoriels d'innovation. La comparaison entre les secteurs du café et des produits laitiers révèle ainsi que les stratégies des acteurs du café sont limitées. En ce qui concerne l'élaboration des politiques, cette thèse contribue aux politiques d'accompagnement de l'adaptation au niveau des ménages, aux politiques de recherche agronomique et de négociation des accords internationaux. Les recommandations politiques au niveau des ménages se différentient selon trois scénarios. En premier lieu de l'intensification dans le café par l'innovation technologique. Les deux autres options politiques sont dans la diversification sectorielle dans la production laitière qui dépend de leur niveau de rentabilité. Les résultats de cette étude sont issus d'enquêtes sur l'analyse des systèmes d'innovation. D'autres options politiques sont proposées dans le développement de nouvelles infrastructures, des subventions pour accroitre les potentiels d'adaptation. Nous recommandons enfin de nouveaux sujets de recherche pour le futur.

Mots clés: Changement climatique; Système agroforestier; Intensification; La sécurité alimentaire; Système d'innovation

RESUMEN

El cambio y la variabilidad del clima son un gran desafío para la producción y la productividad agrícola, especialmente en los trópicos. El sector del café es sensible al cambio climático, ya que requiere una temperatura relativamente fría y aportes de lluvia equilibrados durante la estación de crecimiento. Por lo tanto, es fundamental comprender las posibilidades de adaptación a los impactos del cambio climático en la producción de café, evaluado los límites de la adaptación, las barreras y las oportunidades. El objetivo de esta Tesis es analizar las estrategias de adaptación al cambio climático en la región central de Kenia. Se estudiaron tres componentes de la adaptación, que incluyen: A) motivación para la adaptación, que se basa en el conocimiento sobre el cambio climático y la adaptación por parte de los agricultores, B) la respuesta de los agricultores, analizada por medio de las opciones actuales que los hogares y sus determinantes, y C) el contexto para apoyar la adaptación. Este estudio se basó en cuatro fuentes de información: (1) discusiones de grupos focales para predefinir los cuestionarios a los productores, (2) encuestas de hogares productores, (3) entrevistas de los interesados y (4) datos históricos del clima. La recolección de datos consideró cuatro tipologías de sistemas agrarios, que incluyen: cultivos alimentarios, café especializado, cafetería diversificada y sistemas lecheros especializados en las zonas cafetaleras y cultivos alimentarios. Se utilizó el análisis de tendencias de Mann-Kendal y el estimador de pendientes de Sen para comparar el conocimiento de los agricultores sobre el cambio climático con los datos climáticos históricos, mientras que el modelo de Heckman se utilizó para analizar estrategias de adaptación y sus determinantes. Los resultados muestran que los cambios en el clima son consistentes entre el conocimiento de los agricultores y el análisis de los datos históricos de la temperatura, mientras que se observa inconsistencia en el cambio de precipitaciones. El análisis de la percepción de los agricultores reveló que las precipitaciones están disminuyendo radicalmente con el tiempo, mientras que no hay evidencia en el registro de precipitaciones que se encuentre para apoyar la percepción de los agricultores. La inconsistencia es, por lo tanto, corroborada con el análisis de patrones. Los agricultores de café y de cultivos alimentarios se adaptan a estos cambios de clima actual de manera diferente. Los agricultores que son conscientes de los cambios se encuentran más dispuestos a explorar las estrategias de adaptación aunque algunos de los agricultores que no perciben que el clima está cambiando también están adoptando estrategias para factores distintos de la percepción. La comparación entre el café y los sectores lácteos determinó que los actores del café son limitados, el sistema está altamente centralizado, con escasas opciones para que los agricultores procesen y comercialicen sus productos, mientras que el sector lácteo está informalmente controlado por negocios basados en la demanda y comparativamente numerosos actores. El análisis concluye que los patrones de precipitación afectan las actividades agrícolas en las zonas de mayor altitud y esto determina la percepción de los agricultores. En consecuencia, los agricultores adoptan una serie de estrategias de adaptación en respuesta a su percepción de los cambios en el clima y la presión económica en su explotación. Esta adaptación al cambio climático también depende de la naturaleza de la interacción de los actores y del contexto institucional. En relación con el desarrollo de políticas, esta Tesis contribuye a las políticas de adaptación a nivel de hogares, políticas de investigación y acuerdos y negociaciones internacionales. Las recomendaciones de política a nivel de hogares consta de tres escenarios. Primero, intensificación de los agricultores en el café aplicando las innovaciones tecnológicas adecuadas. La segunda y tercera opciones de política son la diversificación a los productos lácteos y la transformación sectorial completa en productos lácteos en función de la rentabilidad y el nivel de adaptación de los sectores. Los resultados de este estudio se derivan de encuestas y análisis de sistemas de innovación. Otras estrategias como el desarrollo de nuevas infraestructuras y los subsidios institucionales podrían ser potenciales para la adaptación. Por lo tanto, recomendamos, estos podrían ser futuros temas de investigación potenciales.

Palabras claves: Cambio climático; Sistema agroforestal; Intensificación; Sistema de café; Sistema de innovación

CHAPTER ONE

INTRODUCTION OF THE THESIS

1. INTRODUCTION

1.1. Overall challenges of climate change

Recent reports, particularly in the last three decades have shown an increase in global food demand. The food and agricultural organization (FAO), projects that demand for cereals, for instance, will increase by 70 percent by 2050, and will double in many low income countries (Smith *et al.,* 2006). Demand for livestock products, such as meat and milk have been also increased in the last decades, and are expected to be higher for the future, especially in developing countries as a result of human population growth, income growth, and urbanization (Thornton, 2010). Studies, however, indicate that agriculture is negatively affected by climate change (Comoé *et al*., 2014; Bardaji & Iraizoz, 2014; Karrer & Barjolle, 2012; Bryan *et al.*, 2013; Lobell *et al.,* 2008; Deressa & Hassan, 2009). Future livestock production will increasingly be affected by competition for natural resources, particularly land, and water due to climate change derived challenges (Thornton, 2010; Angeon & Caron, 2009). The fourth Intergovernmental Panel on Climate Change (IPCC, 2007), for instance, states that Global Green House Gas (GHG) emissions have grown since pre-industrial times, with an increase of 70% between 1970 and 2004. Continued GHG emissions causes further warming and induce many changes in the environment and global climate system. Trend analysis based on observed changes by IPCC, (2013) indicates that both minimum and maximum temperatures increased by 2.2 and 2.5°C respectively. Similarly, rainfall experienced a high degree of variability and decline (Rosell and Holmer, 2007).

Regarding the future climate uncertainties, the Fifth Assessment Report (AR5) of the IPCC, projects changes in global temperature and rainfall looking at all the four RCPs (Figure 1). Average global temperature is, therefore, projected to increase by up to 4.8 ^{0}C over the 21st century (IPCC, 2014). The report also predicts that the Arctic region will warm more rapidly than the global mean, and mean warming over land will be larger than over the ocean. Mean annual temperature rise for Africa, relative to the 20th century projects to exceed by 2^{0}C at the mid of the 21st century and 3-6 ^{0}C by the end of the century (IPCC, 2014). The increase in greenhouse gas emissions (See Figure 1), which is raising the Earth's temperature, is expected to further leading to climatic impacts, such as changes in rainfall patterns, and more frequency of extreme events, such as drought and flooding (Stocker *et al.,* 2013, IPCC, 2007). This estimation trends shows a different quantitative measures for different scenarios (see Figure 1).

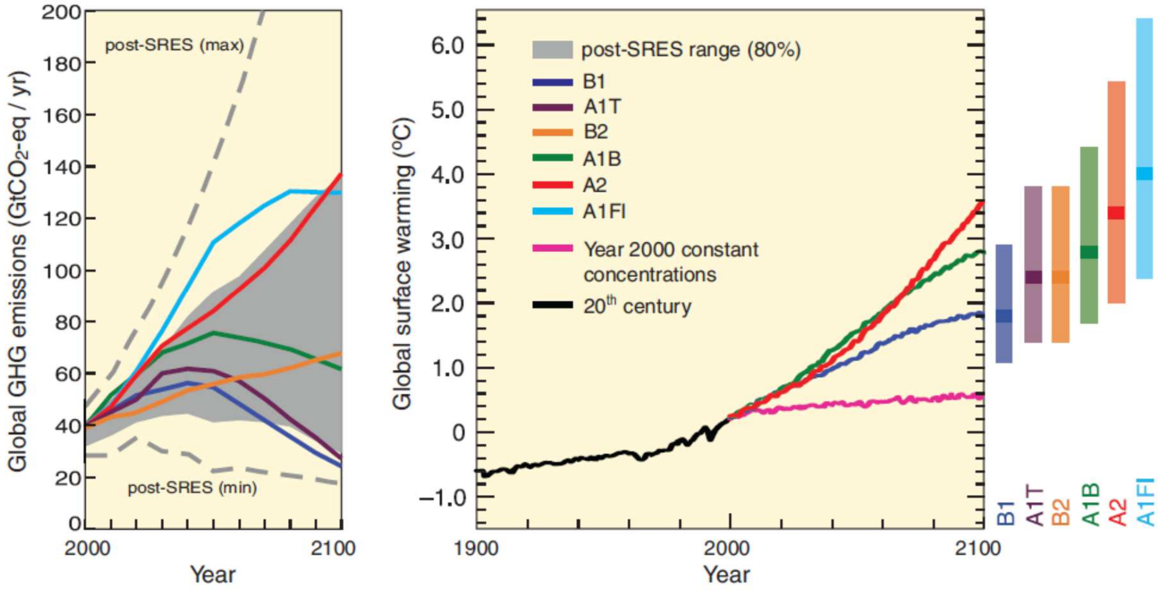


Figure 1 : Scenarios for GHG emissions from 2000 to 2100 (in the absence of additional climate policies) and projections of surface temperatures between 2000 and 2100

Source: IPCC, 2014

Unlike temperature, predictions on rainfall are less consistency for global, regional, and local scales. The IPCCs fifth assessment (IPCC, 2014) concludes, at global-scale, rainfall is projected to gradually increase in the 21st century with a smaller significance. Regionally, the Northern hemisphere mid-latitude land areas do show a likely overall increase in rainfall, while the situation in the warmer regions will not be uniform; with some regions experiencing increase, and others decrease, or the change is insignificant. This general pattern has been evidenced in previous studies, as wet regions get-wetter and dry regions get-drier (Held and Soden, 2006; Chou *et al*., 2009; Allan *et al*., 2010). Regional analysis evidence an expected reduction in rainfall over North Africa (Giorgi and Lionello, 2008; Patricola and cook, 2010), West Africa (Fontaine *et al.*, 2011; Druyan 2011; Biasutti *et al.,* 2008), southern Africa (Moise and Hudson, 2008; Shongwe *et al.,* 2009), while inconsistency is observed in Eastern Africa. Over the entire continent, excluding Eastern Africa, the past events, and future projections in rainfall are consistently a decreasing trend. In the Eastern part, however, inconsistency is observed between historical events, and future projections. Over the last three decades for instance, rainfall has declined significantly (Funk *et al*., 2008). Williams *et al*. (2012) explored a significant decline in monsoon rainfall in the region. Unlike past experiences, there is no consensus among scholars on future projections of Eastern Africa. Williams and Funk (2011) and Funk *et al.* (2008) suggests the probability of wetter climate by the end of 21st century, while Patricola and Cook (2011) predicts drying over East African countries, such as Uganda, Kenya, south Sudan and Ethiopia. This high degree of temporal, and spatial variability is expected to be related to a variety of physical processes (Rosell and Holmer, 2007), complex topography (Conway and Schipper, 2011) of the region.

Specific evidence from Kenya, indicated temperatures has risen and rainfall has declined in most parts of the country (Gov Kenya, 2010). Since the early 1960s, minimum (night time) temperature have risen by 0.7-2.0 ^{0}C, and maximum (day time) temperature have risen by 0.2-1.3 ^{0}C depending on seasonal, and regional differences (see appendix 4). In Central province for instance minimum temperature has increased by up to 2.0 and maximum temperature up to 0.7 ^{0}C between the periods of 1960 and 2010 (Gov Kenya, 2010). Ranges of climate models (Bryan *et al*., 2013; Schlenker and Lobell, 2010), suggest mean temperature increase is expected between 3 C^{o} and 4 C^{o} by the end of the 21st century.

Regarding rainfall in Kenya, low to highly decreasing trends are manifested in the annual rainfall series particularly the long rain season over most areas of the country comparing the situation in 2060s with the current trends (Gov Kenya, 2010). Linke *et al*, 2015 substantiated this, presenting evidences of increasing inter annual rainfall variability and higher occurrences of drought events. This increasing temperature coupled with the decreasing rainfall and higher occurrences of drought became the reason for the decline of agricultural produce (Linke *et al.*, 2015). The situation is exacerbated by the high dependence on climate sensitive natural resources base and rainfed agriculture with low level of technological application to agriculture (Gov of Kenya, 2015).

1.2. Impacts of climate change

Climate change and variability is not uniform throughout the globe and time frame, where rate of change differs spatially and temporally. Changes are higher in some regions, while it is lower to other regions (Figure 2). The regional variability in climate also yields variability in impacts (Figure 2). Yield increase is expected at some high altitude regions of the northern hemisphere, while a significant decrease is expected at the lower altitudes, which force the global production to take declining trend (Figure 2). In the tropics, negative yield impacts are highly expected (Molua, 2010; Lobbell *et al.,* 2008; IPCC, 2014). In Northern countries, such as North Europe, a net productivity increase of 30-35% are projected (Iglesias et al., 2009), while the highest negative impact is projected in Africa (Lobell *et al.,* 2008; Stocker *et al.*, 2013; Molua, 2009). Impacts are also different to different enterprises, such agriculture, forestry, or other sectors. From the agriculture sector for instance, in Africa and Latin America, maize production is expected to decline by 10% in relation to climate change, which would be a reason for the loss of $2 billion per year as of 2055 comparing to the current production (Jones & Thornton 2009).

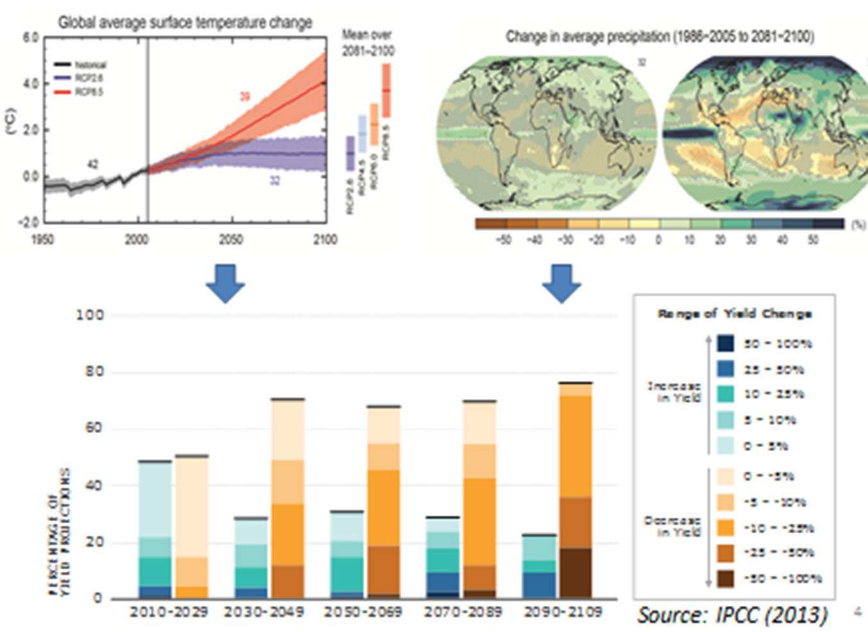


Figure 2 : The projected changes in crops yield as a function of increasing temperature and variable rainfall over time. The Figure indicates the projected (1) Temperature (2) Rainfall, and (3) Production change for the years1950-2100.

1.2.1. Impacts of climate change in tropical countries

The impacts of climate change in agriculture is much more visible in the tropics; its food production systems are among the most vulnerable due to its extensive reliance on rainfed crops production, recurrent droughts and high variability in climate (Boko *et al.,* 2008; Molua 2012). This comprises decline in yield of major cereal crops (Lobell, 2008; Liu *et al*., 2008; IPCC, 2013), decrease in quality of livestock products and loss of livestock herd size due to feed shortage (Jones & Thornton, 2009; Herrero *et al.*, 2014; Seo, 2010), limit opportunities to diversify household livelihoods (Bernstein *et al.,* 2007; *Linke et al*., 2015) and loss of productivity of high value crops such as coffee and tea (Popular & Laderach, 2014; Eitzinger *et al.,* 2014; Laderach *et al.,* 2011). Wheeler & von Braun (2013) stated climate change interrupts progress towards world without hunger and Ollat *et al.* (2016) evidenced the quality of cash crops depended on climate patterns.

Since the temperature is expected to increase and rainfall to be highly variable, along the 21st century compare to the previous centuries, climate impacts will be more sever to affect crop production and location (IPCC, 2014). Yields from rain fed agriculture could be reduced by up to 50 percent by 2020 (IPCC, 2007). In Africa and Latin America, maize production is expected to decline in relation to climate change which would be a cause for the loss of $2 billion per year as of 2055 compared to the current production (Jones & Thornton 2009). In sub-Saharan Africa alone, projections predict a loss of 10-20 million hectares of land suitable for double cropping and a loss of 5-10 million hectares of land suitable for triple cropping (Fischer *et al.,* 2005; Schmidhuber & Tubiello, 2007). The various environmental impacts of agricultural intensification and food production, with negative impacts on soil and biodiversity, result in adverse feedbacks on climate, food security and on-farm income at different scales (Stocker *et al*., 2013).

The change and variability in climate patterns over recent decades is not only affecting annual crops but have already impacted perennial cash crops, such as coffee and Cocoa (Craparo *et al.*, 2015), wine and grape (Touzard, 2015; Vitivin, 2013; Boyer *et al.,* 2016) and tea (Wijeratne & Anandacumaraswamy, 2007). Changes in climatic patterns mainly increased in temperature over the past decades has mainly resulted in changes in grapes phonological stages and harvest date, accompanied by an increase in grapes sugar content and a decrease in level of acidity (Ollat & Touzard, 2014).

Suitable agro-climatic zones for growing economically important perennial crops, such as coffee is significantly diminishing and being replaced by other annual crops such as cereals (Laderach *et al.,* 2011). In Mesoamerica, for instance Castellanos *et al.* (2013), finds climate change as one of the major challenges for coffee producers challenge in their economy, which forces them to look other source of income for their livelihood. Coffee farmers in Guatemala, Honduras and Mexico have been experiencing extreme weather events which eventually caused farmers' deficiency of income (Tucker *et al.,* 2010).

Future projections indicate the lower altitudes of Mesoamerica is expected to be less suitable for future production of coffee Arabica, while the higher elevations of South America, which is close to the equator to be benefited due to the expansion space (Ovalle-Rivera *et al.,* 2015)**.** In the highlands of Eastern Africa, such as the Southern and Western Ethiopia, and Central Kenya, potential coffee areas may be more marginal, currently suitable zones for coffee may be unsuitable in the future (Davis *et al.,* 2012).

Studies on the previous trends and the future projections (Ovalle-Rivera *et al*., 2015; Davis *et al.*, 2012; Jaramillo *et al.,* 2009) explored the need to adapt to the changing climate as it will have different vulnerabilities and challenges to producers. Particularly to Kenya and Ethiopia, adaptation comprises different strategies where taking advantage of the higher altitudes of climatically and ecologically suitable area to expand production is among the choices with lower risk (Ovalle-Rivera *et al.,* 2015). This drastic shift in current land use and crop suitability is therefore, a function of climate change. These adaptation strategies are however, allow a land use change to continue and the farmers at the lower altitude continues to be impacted. Other adaptation strategies are therefore requiring maintaining coffee at its current production area.

1.3. The need for adaptation and mitigation

The historical analysis and future projection that indicate a significant decline in crops production and natural environmental degradation calls for innovations to adapt the changing climate (Bardaji and Iglesias, 2014). Adaptation in this context is defined as "the process of adjustment to actual or expected climate and its effects, which seeks to moderate harm or exploit beneficial opportunities" (IPCC 2014). This could be undertaken through technological developments that tackle current challenges, government programs and insurance to strengthen capacity (Smit & Skinner 2002; Mwalusepo *et al*., 2015), farmers' farm technical production and practices (Bryan *et al*., 2013; Silvestre *et al*., 2012; Maddison, 2007), and institutional reformation and financial provision (Smit & Skinner 2002). The process of adaptation to climate change requires different agents (producers, institutions, food industries) which is a precondition for systems of innovation and actors interaction at different scales (from individual to global scale) (Wreford *et al.*, 2010)

At international level, the international community has been organizing different discussions on how to mitigate and adapt the ever-changing climate. The Kyoto protocol, for instance, was an example of the willingness of some industrialized countries to reduce average GHG emissions by 5.2% in 2012 compared to 1990 (IPCC, 2007). The Copenhagen accord of the 2009 United Nations Framework Convention on Climate Change (UNFCCC) Conference of the parties recognized that 'the increase in global temperature should be below 2°C' to avoid severe impacts. However, current emission trends suggest that a 2ºC target will be extremely difficult to meet. It requires global emission reductions until 2050 of more than 70 percent (Leemans *et al.,* 2009).

The COP 21(21st Conference of Parties of the United Nations Framework Convention on Climate Change, UNFCCC, 2015) of the Paris conference, on the other hand, was on the practical realization and implementations of the former decisions but also emphasized on the adaptation and mitigation of agriculture to climate change. The scientific and political commitment to limit emissions and the provision of targets from all the member countries was one step forward in the adaptation process. This was emphasized on the roles of agro-ecological practices such as agroforestry to absorb emissions and carbon storage in order to reduce emission to below 2 ^{0}C. The level of commitment and priorities of each country in support of the Paris Agreement were made explicit in their intended nationally determined contributions (INDCs), wherein they specified the ways and means they would use to address climate change in their country, through both mitigation and adaptation measures, and committed themselves to take appropriate actions to reach their specified goals. African countries such as Kenya are among the countries submitted their mitigation and adaptation targets.

At national level in Kenya, the National Climate Change Response Strategy (NCCRS) developed in 2010 was the first policy response document and guideline on mitigation, adaptation, technology, finance and governance of climate change (Gov Kenya, 2010). The main focus was ensuring adaptation and mitigation is integrated in all government planning, budgeting and objectives. This policy guideline outlined the vulnerable sectors and the possible adaptation and mitigation strategies including sources of finance and means of implementation of national level projects and programs. In relation to the enhanced understanding of climate change vulnerability of the nation from the NCCRS guideline, National Climate Change Action Plan (NCCAP) was developed in 2012 to take one step the implementation of adaptation and mitigation strategies of the NCCRS. This was emphasized on the subcomponents of long-term low carbon development strategy through emission abatement (Appendix 3), enabling policy and regulatory framework, National Adaptation Plans (NAPAs), Nationally Appropriate Mitigation Actions (MEMAs), National Technology Action Plan, and Climate Finance. The NCCAP sets out a vision for a low carbon climate resilient development pathway; summarizes analysis of mitigation and adaptation options and recommended actions; recommends an enabling policy and regulatory framework; and sets out next steps for knowledge management and capacity development, technology requirements, a financial mechanism, and a national performance and benefit measurement system (Gov Kenya, 2013).

In relation to the COP 21 Paris agreement, Kenya has developed the Intended Nationally Determined Contributions (INDCs 2015) to setting targets and operationalizes the former policies and strategies to implement the actions (Gov Kenya, 2015). One of the targets is to reduce emissions by 30 % of the total 143 million tonnes of carbon dioxide equivalent projected for 2030 (see Appendix Figure 3). The livestock, agriculture and forestry sectors are the largest emitters in Kenya, accounting for approximately 67% of emissions in 2010 and 40 per cent in 2030, where the roles of agro-ecological practices is proposed among the top emission abatement strategies (Gov Kenya, 2015).

These international and national macro level actions are insufficient unless these government and organizational level agreements are supported by the micro level commitments, such as farmers, who are the direct hit of the changes, and direct implementers of strategies to respond. Farm level adaptation response to climate change, in this regard, is integrated with human development to generate no regrets, co-benefit strategies (Butler *et al.,* 2014). This cognitive response provides a potentially useful decision-making framework through the steer of societies towards sustainable future and takes appropriate actions. This is determined by the behavioral barriers among individuals, which are specifically related to the psychological and thought processes of individual actors to react to the changes. A barrier in perception of climate change is one of the preconditions for adaptive response (Shameem *et al.,* 2015). Policy interventions, and actions could be achievable, if the perceptions and attitudes of the implementing communities is understood and considered. Moreover, this climate change perception has to be preceded by a practical implementation of different strategies.

The micro farm level adaptation are the farmers' investment in climate smart practice, focuses on farm tactical decisions in response to seasonal variations in climatic and other factors (Comoé *et al.* 2014; Molua, 2014; Ollat & Touzard, 2014; Ollat & Touzard, 2005). This requires greater investments in climate smart practices, such as drought and heat tolerant varieties, supplemental irrigation, and integrated strategies to reduce livelihood risks (Molua*,* 2014; Arslan *et al.,* 2015; Bryan *et al.*, 2013; Howden *et al*., 2007). These strategies can notably reduce climate change vulnerability by making farm households better able to adjust to the changing climate, and these help to avoid or reduce potential damages (IPCC, 2014). Supporting agricultural production and intensification requires the provision of nontechnical services of marketing and financial support. Individual farmers have to be part of different institutions either in groups or individual level and the institutions need to innovate on how the livelihood of the farmers have to be improved (Boyer, 2016). This takes the third dimension in the adaptation to climate, the institutional innovation and transformation towards adaptation.

1.4. Agriculture in the climate change context

In mono-crop agriculture, increasing temperature and erratic rainfall would increase fertilizer requirement for the same production targets; and result in higher emissions. This confirms the agricultural sector is an emitter of greenhouse gases to the environment. It directly accounts for 14% of global GHG emissions in CO_2 equivalents and indirectly accounts for an additional 17% of emissions when land use and conversion for crops and pasture are included in the calculations (IPCC, 2007; World Bank, 2010). Although Kenya's total GHG emissions are relatively low, accounting 73 MtCO2eq in 2010 (Appendix 3), land use, land-use change and agriculture sectors contribute the largest portion of the total emissions (Gov. Kenya, 2015).

Agricultural sector particularly in developing countries is also adversely affected by climate change, which threatens food production (Angeon, 2012; Mbow *et al*., 2014). This is in the form of impacts on yield, quality, and agricultural stability. The AR5 of the IPCC predicts a decline in yields and production of staple foods such as wheat, rice and maize (IPCC, 2014). Future projections expressed as changes in climate are expected to increase, impacts and risks associated with climate change will be more severe (Field *et al.,* 2014; Garcia de Jalon, *et al,* 2014). Coffee farming is also one of the most affected by the climate change as part of the agricultural sector (Lin, 2007; Jaramillo *et al*., 2011; Davis *et al.,* 2012; Ovalle-Rivera *et al.,* 2015). Land use and crop (coffee) suitability may reduce by 35-50 per cent in Nicaragua and Mexico (Laderach *et al.,* 2011) and 30-35 per cent in Kenya (Laderach *et al*., 2014) by 2050. Specific to the study area, coffee used to grow at lower altitudes (below 1500 meters above sea level) especially in the 1960s and 1970s as low as 1000metters above sea level. To date, however, altitudes between 1400 through1600 meters above sea level is marginal coffee zone where as potential coffee zone area is between 1600 and 1950 meters above sea level due to different factors.

1.5. Rational of coffee agroforestry to contribute to adaptation and food security in the context of climate change

Mono-crop agriculture is both a victim of climate change and an emitter of GHG. Regarding sustainability of agriculture in the future, Iglesias *et al*., (2011) raised three challenging questions linked to adaptation: How can agriculture deal with an uncertain future? How do local vulnerabilities and global disparities respond to this uncertain future? How do we prioritize adaptation to best address the risks resulting from climate change? In short, these three questions addresses the need for adaptation, the regional and local disparities of climate change, which leads to differences in adaptation, and the way adaptation strategies has to be prioritize. Adaptation to climate change in agriculture in general and perennial cash crops in particular and its relationship with food security should also depend on the activities of research and innovation (Ollat & Touzard, 2005; Touzard, 2012). Boyer et al (2016), finds climate change is affecting French Vineyards both the agronomic and product quality, where innovations to adapt are prioritized.

At the core of the Africa's food security and poverty debate, there is always the role of agriculture in ensuring food security, and how it is challenged by climate change. A consensus emerging is that a new approach to development must of necessity focus on sustainable food and environmental security. This should be on how to move from high input-high emission agriculture to low input-low emission agriculture as a pre-requisite for food security and climate change adaptation and mitigation strategy. Scholars such as Angeon *et al*. (2014); Simane *et al*. (2016); Altieri, (1995) argues the need to adopt efficient farming systems to different localities and recommends a fundamental shift towards agroecology as an approach to boost food production and improve the situation of the poor. In such cases, the agroforestry system gets credit to maintain the environment, while providing food security and social values. In developing countries, where economies, and livelihoods depend largely on ecosystem services, the multi-functionality of agroforestry is higher, and it has to be taken in to account for communities' resiliency (Vignola *et al.*, 2009).

Studies for instance, highlighted agroforestry systems use to mitigate and adapt climate change (Lasco *et al.*, 2014; Luedeling *et al.*, 2014; Lin, 2007), conserve resources use and facilitate low input practices (Carsan *et al.,* 2014a), source of socio-economic and livelihood sources, such as source of food and feed (Mbow *et al.,* 2014).

Large portion of food is grown in tropical agroforestry systems, where climate favors for productivity (Slingo *et al*., 2005). Coffee as a perennial crop, most of the time grown in agroforestry systems of the tropics, where mixed crop-livestock is assumed as one of the sustainable production, and resilient to climate (Alary *et al.,* 2016). In Kenya, for instance, farmers integrate food crops and livestock with coffee in different proportion and mixing typologies. Coffee agroforestry, in this regard, contributes to food security in two ways. 1) Increased income from coffee, which is internationally traded at the international market and improve farmers' purchasing power of food crops. And 2) increased domestic production of food crops. In Kenya, the coffee sector is one of the key pillars of the country's economy, and employment means mainly of the rural poor (Gov. Kenya, 2007). Purchasing power of food by coffee farmers is always affected by the quality and quantity of production per year as well as the market value of coffee at the local and international market (Carsan *et al.*, 2014b). Regarding to self-production and consumption, on the other hand, trees inside and outside coffee plots contribute to household food security (Mbow *et al.,* 2014; Cerdán *et al*., 2012). Improved systems, such as intercropping with legumes reduce reliance on fertilizer by 50%, which further maximizes purchasing power of additional food (Carsan *et al.*, 2014a). In the mixed crop-livestock agroforestry system, livestock also contributes a large share for household income and integrated farms are more resilient than monoculture (Iraizoz *et al.,* 2011; Seo, 2010; Bell & Moore, 2012).

The rational and subject of the Thesis is therefore, in the field of the importance of agro-ecology, particularly coffee agroforestry for adaptation in the context of climate change in Kenya. But another question that has to be addressed here is what is the rational to choose a Kenyan case study? Why Kenya is best example and representative?

Kenya is one of the countries highly hit by climate change (Bryant *et al.,* 2013; Lobell, 2008; Bilham, 2011). Yield decline of some major perennial crops, such as coffee and land use change are among the impacts, which are caused by climate change (Opiyo *et el.,* 2015; Laderach *et al.*, 2014). Coffee used to grow potentially at the mid and marginally at the lower altitudes of Central province, some three decades back. Currently, however, the lower altitude coffee farms are changed to food crops farms, such as maize and beans while at the mid altitude, diversification to dairy and other enterprises is becoming common. Future projections (Laderach *et al.*, 2011) show coffee to move upwards to the higher altitudes due to the reduced suitability from the lower altitude. The case study of the agroforestry of Kenya, therefore, represents an area with different agro-climatic zones which permits us to understand which agro-ecology is mostly affected by climate change, what land use systems are changing as a result of the changes, and what adaptation strategies are needed to the particular climatic zone.

1.6. Problem description

Adaptation and mitigation to climate change is important to address impacts, but there are barriers, limits and costs. Despite researches on the need to adapt to climate change (Field *et al*., 2014; Brooks *et al.,* 2006; Thornton *et al.,* 2009), and the impacts of climate change on agricultural production (Wang *et al.*, 2011; Di Falco *et al*., 2011; Moore *et al*., 2009; Parry *et al.,* 2004), particular studies on the adaptation steps, and strategies specific to the coffee agroforestry systems are insufficient. This research was, therefore, intended to identify appropriate adaptation strategies that counter the Impacts, and strengthen farmers' adaptive capacity. Farmers need to develop site-specific strategies tailored to their environments. Adaptation to climate change, therefore, requires that farmers, first notice the climate has indeed altered, understand strategies are imperative, and institutional reformation that could provide favorable condition for adaptation. Consequently, the initial question of this research was to understand the adaptation strategies pertinently at the coffee agroforestry systems of Kenya. This potentially looks at the three steps in the adaptation process. (1) The cognitive and behavioral change of farmers' towards adaptation, which contains different knowledge and perception base and the comparison, whether this cognitive knowledge of farmers corresponds with the measured historical climate data. (2) Series of current adaptation choices and future needs, which are technical and farmers' practice. (3) The systems of innovation and institutional variables, which are important for the uptake of different adaptation strategies. In order to attain the principal objective, the overall study considers three specific objectives that are detailed to sub objectives in the independent chapters of the study.

The specific objectives of this study are therefore, to:-

i. Analyze and compare (if there is synergy) farmers' knowledge of climate change with the time series historical climate data of temperature and rainfall as a function of climate change adaptation;
ii. Explore the current choices of farm level adaptation strategies to climate change and the determinants of farmers' choice of adaptation strategies; and
iii. Analyze the roles of systems of innovation in the uptake of climate change adaptation strategies in the agroforestry systems of Central Kenya.

1.7. Theoretical and conceptual framework

1.7.1. Disciplinary base: innovation studies and the application of innovation economics in climate change adaptation

Conceptually, this Thesis was established at the interface of three interlinked but self-exhaustive concepts, i.e. (1) the knowledge base of climate change adaptation, (2) farmers' investment and practice to adapt to climate change and its determinants, which is part of the technological innovation (Carlsson, 2012; Lundvall, 2010), and (3) the application of institutional innovation and systems of innovation approach (Edquist and Johnson, 1997) particular to the dairy and coffee sector which combines institutional and sectoral systems of innovation to develop kinds of adaptation tools. in connection to this, the strategies to adapt to climate change claims its dependence on the knowledge and perception level of the actors, the current capacity and opportunities to take actions and the institutional context to permit the coordinated actors interaction.

Generally, the Thesis is in the field of "Innovation economics, and Economics of adaptation". The knowledge base of climate change adaptation and farmers' investment to adapt collectively uses the concept of economics of adaptation, while the institutional innovation potentially uses the innovation economics. In this Thesis, we used the definition of innovation economics as defined by Courvisanos & Mackenzie (2014); Korres & Drakopoulos (2009); Gopalakrishnan & Damanpour (1997) defined as a body of economic theory that contends *a* priori that economic development is the result of appropriated knowledge, innovation and adaptation operating within an institutional environment of systems of innovation. Market place and production is characterized by the interaction and interplay of social, economic, and technological changes, where change is considered as omnipresent and pervasive, and innovation facilitates the process of adaptation. Here, the concept of innovation plays a role in nurturing the economy, in enhancing and sustaining the high performance of firms, in building industrial competitiveness (Gopalakrishnan & Damanpour, 1997). But this innovation economics is based on the theory of evolutionary economics, which was previously developed and used by Nelson and Winter (1977) raising a question "why economics is not evolutionary".

The works of Schumpeter, and other evolutionary economists, which were the basics for the upcoming of innovation economics distinguished four streams. The first stream in the evolutionary economics is mainly about micro-economic approach, which is based on the duality of business and market selection, and the study of phenomena of learning, and organizational change (Malerba *et al.,* 2007)**.** The second stream is on the evolution of institutions, norms, preferences, sector or industry dynamics (Wilsford, 1994; Arthur, 1989). The third stream focuses on the analysis of economic growth and technological innovation (Fagerberg and Verspagen, 2002; Yildizoglu, 2009), and the fourth stream is mainly on the dynamics and typologies of systems of innovation, such as National System of Innovation (Carlsson *et al.,* 2002), Regional System of Innovation (Cooke, 2001), Sectoral System of Innovation (Malerba, 2002; Bocconi & Sarfatti, 2000), or Agricultural System of Innovation (Kilelu *et al.*, 2013). This highlights the evolutionary process, and distinguishes innovation economics from other branches of economics, including mainstream neoclassical theory, which views capital accumulation as the primary driver of economic development. Unlike the other branches and classes of economics, the systems of innovation approach as part of innovation economics is the dynamic view of the innovation process. This argues that the dynamic, innovation-driven development of the economy is not the domain of, and cannot be explained by, neoclassical economic or other theories (Courvisanos & Mackenzie , 2014). It also unravels, why we choose this Thesis to lay down in the field of the innovation economics and economics of adaptation.

This Thesis was, therefore, set under the theoretical and analytical approach of evolutionary theory and the systems approach. The evolutionary theory, which is a broader camp, but in relation to this Thesis, first emphasizes on key concepts, such as learning, knowledge, competencies, capacities and dynamics (Malerba, 2002; Edquist, 1997, Freeman, 1987). Learning and knowledge, which are the function of long-term process and exposure are key elements in the change of economic system. Agents in different sectors, such as the climate change adaptation agents in agriculture learn, search and act in uncertain and changing environments (Malerba, 2002), where climate change could be the reason of changing the environment.

Second, the evolutionary theory emphasizes on the reaction of actors in response to their learning and knowledge. The adaptation actions to climate change by different actors at different levels is part of this reaction to the predetermined knowledge and learning. This includes for example farmers' perception of climate change and other actors or partners knowledge of climate change. This coordinated action between actors to respond to changes leads to a third category of contribution of evolutionary theory. This is the tradition of links and interdependencies among sectors and actors (Malerba, 2002). This boundaries of links and interdependencies are not fixed but changes over time. Sector wise, from the study area for instance, suitability of coffee from the lower altitude is decreasing and from the upper altitude is increasing, which creates mixed type of farming at some places. Accordingly, actors and their interaction also changes. The last group of contribution of evolutionary theory we considered in this Thesis is the system of innovation approach, which considers innovation as an iterative process among wide variety of actors. This includes how the actors in the adaptation process to the different sectors such as coffee and dairy of the study area interact. This considers innovation as a collective process.

In connection to the evolutionary theory and systems of innovation approach, which emphasis on iterative learning and actors interaction, qualitative studies often find that the sensitivity of agricultural systems to climate are rarely attributed to solely changes in some exposure, or in the adaptive capacities to respond to the exposure, as assumed in crop models; instead sensitivities can be seen as pathways over time (Sallu *et al*., 2010). Farmers' cognition and social institutions are considered as the basics in adaptation steps to climate change (Armah *et al.*, 2015)**.** Having understood the climate has indeed altered, and strategies are imperative, farmers then, need to identify potentially useful and feasible innovative adaptation strategies for implementation.

Adaptation to climate change is a multi-faceted progress which therefore creates farmers adaptive capacity. The process of adaptation requires four elements (see Figure 3) notably, the cognitive and behavioral change of farmers (Armah *et al.,* 2015; Frank *et al.*, 2011; Dhanya & Ramachandran, 2015; Tucker *et al*., 2010), technical implementation of series of appropriate practices and investments (Karrer and Barjolle, 2012; García de Jalón *et al.*, 2014; Deressa, 2008; Gebrehiwot & Van Der Veen, 2013), the institutional and organizational arrangement towards adaptation (Schmitt *et al.,* 2013; Frank *et al.,* 2011), and temporary or permanent migration (Mathenge et al, 2015; Bryan et al, 2012). In his study, García de Jalón *et al*. (2015) explained the steps in adaptation as limits to adaptation providing how thus impedes capacity to adapt. Frank *et al.* (2011), expressed the crucial roles of socio-cognitive element on adaptation and selection of strategies, stating previous investigations were focused on socio-economic and socio-technical elements. Farmers of high level of socio-cognitive are likely to adapt different adaptation strategies as social condition is the pre-requisite for farmers to get motivated and therefore, act upon it.

The system of innovation perspective in adapting to changes considers knowledge as a strategic and fundamental capital for innovation (Foray, 2010; Godin, 2006; Barjolle and Chappuis, 2000). This is not, however, the only requirement for successful adaptation. The innovation process actually comprises five elements. Farmers' knowledge, which includes farmers' first exposure and information to innovation about the technology, or tool, while the second element, farmers' persuasion is the process, where farmers develop a kind of interest, and mind setup towards adoption of the technology, but may or may not require additional information, or asset base. These levels, such as exposure and persuasion are the elements of perception towards the change, and need for adaptation. Farmers' decision, a kind of balance to weight the advantages and disadvantages of the technology, cost-benefit analysis, and an inclination towards adoption or rejection of the technology is determinant for implementation, while at the implementation stage; farmers employ the innovation to varying degrees depending on different opportunities, and decision results (Figure 3). In general terms, the decision, and implementation of adaptation of strategies depend on the way farmers perceive the changes, and whether strategies are imperative. Farmers' perceptions of climatic changes have to be, therefore, center of such adaptation planning studies (Maddison 2007).

Studies from Africa (Okonya *et al.*, 2013; Simelton *et al.*, 2011; Arnell *et al*., 2004; Fosu-Mensah *et al.*, 2012), Asia (Shameem *et al*., 2015; Adger, 1999; Sahu & Mishra, 2013) and Australia (Boon, 2014; Nursey-Bray *et al*., 2012) have suggested that the success of any adaptation measures would depend on a good farmers' perception about climate change and variability. Akponikpè *et al.* (2010) indicated that local knowledge and experience have helped to advance understanding of climate change and its impacts on agriculture. For instance, studies among coffee producers in Central America and Mexico (Tucker *et al.,* 2010; Castellanos *et al.*, 2012), Tanzania (Craparo *et al.*, 2015), semi-arid cattle husbandry in Kenya (Silvestri *et al.*, 2012; Thornton & Gerber, 2010), Maize producers in Ethiopia (Deressa & Hassan, 2009) support the importance of local knowledge and perception of climate as a critical ingredient in guiding policy responses on adaptation. In South Africa and Ethiopia, research highlights the role of perception in understanding the importance of education and awareness building and in identifying available options to enable farmers adapt to changing climate (Bryan *et al., 2009).*

In relation to the second element (see Figure 3), farmers practice and choice of adaptation strategies to climate change demands a substitution of a strategy by another based on accessibility, adoptability, and cost effectiveness in one hand, and utility maximization in the other hand. This study, primarily assumes that the future climate variability, and change may increase the frequency of drought and thus reduce the coping range and adaptive capacity of the vulnerable population. Second, the substitution of scarce resources by the abundant technologies considers the comparative advantage that leads to adoption of the strategies. Third, the adaptation options and choices, however, depend on different factors including inadequate climate information (Deressa *et al*., 2009), partial understanding of climate impacts and uncertainty about benefits of adaptation (Hammill & Tanner, 2011; Iglesias *et al.,* 2010), level of education (Maddison, 2006), disconnect between climate science and policy leading to a lack of use-inspired research (Moser, 2010), insufficient credit access (Bryan et al, 2009), and weak market systems (Bardaji & Iraizoz, 2014; Kabubo-Mariara, 2009).

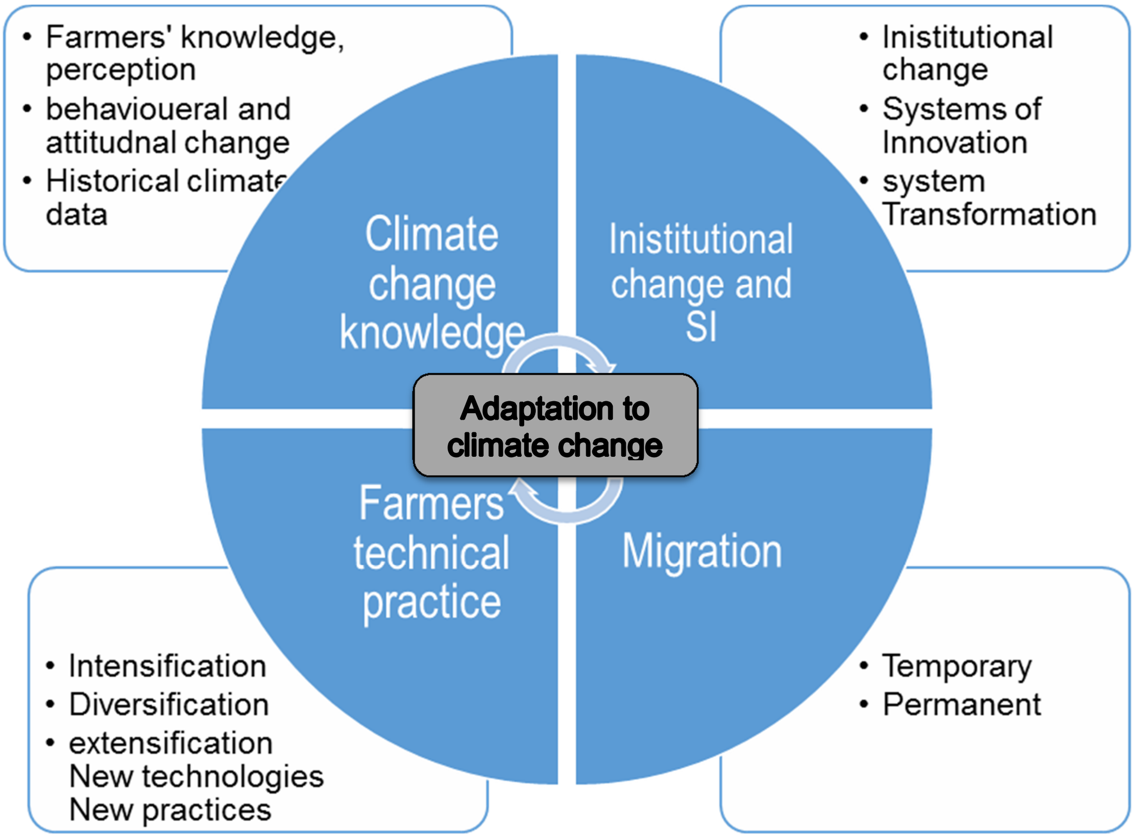


Figure 3 : **The dimensions of farmers' adaptation to climate change**

Regarding the third element, (see Figure 3), the performance of institutions to support farmers implementing the intended adaptation practices shifts the study of adaptation from individual point of view to organized and institutional maters. This supports the argument of the strategies of adaptation to climate change are dependent on the roles of institutions to provide support and create conditions where farmers could implement adaptation practices (Figure 3). In relation to this, the COP 21 of UNFCCC Paris agreement is considered unique in developing Intended Nationally Determined Contributions (INDCs) of every member country. These INDCs are expected to consider different knowledge bases and capacities of different stakeholders in the system. Fourth option, (figure 3) is the permanent or temporary migration. Stojanov *et al*., 2016 stated people have long been migrated for many reasons, where climate change as a pushing factor is among the major factors. Whether the movement is permanent or temporary depends on the severity of the changes and recovery of the challenges in the original place and the opportunity at the final destination after the households moved (Gomez, 2013).

The above figure views the four pillars or dimensions of climate change adaptation strategies. The first two dimensions are completely adopts by the individual farmers while decisions of the third dimension requires a performing institutions. Conceptualizing of the dimensions, however, requires stating of the context and rationality about how the coffee agroforestry contributes to food security and climate change adaptation.

Following the theory of institutional economics, the work on systems of innovation place institutions at the center of analysis. The innovation to improve production and productivity of coffee in the agroforestry systems of Kenya for instance relies on two mutual strategies.

The first strategy was to develop new coffee varieties, which are diseases resistance but similar in other characters with the old varieties of diseases sensitive coffee varieties. This was also perhaps required devising institutions, such as partnership and network between different research institutes, financial services and input suppliers. The second strategy was to improve the dissemination strategies of the new varieties and working on the overall value chain of the coffee sector through improving the cooperative systems. The progress towards the development of the dairy sector as an adaptation strategy also comprises the technological and institutional innovation. This helps in the process of governance change in different organizations providing framework of restructuring. Understanding the determinants of adoption and implementation of adaptation strategies of different technologies

(Ketokivi & Schroeder, 2004), and the interaction between innovation agents, such as researchers, input and output dealers and market and policy actors (Kherallah & Kirsten, 2002) is important. Depending on the above theories, for this research, we therefore, considered three hypotheses:-

- Farmers' knowledge and perception of climate change is inconsistent with the climate knowledge produced from historical climate data. Farmers' capacity to adapt to the changing climate, therefore, depends on their capacity to hybridize knowledge, and level of perception of the changing climate.

- Adaptation to climate change and farmers' choices of strategies results from micro-economic farm level innovation, which is a function of different strategies, and farmers' investment in climate smart innovative practices.

- The micro-economic farm level innovation to adapt to climate change is insufficient unless the actors' interaction and institutional dimensions in the system of innovation to adapt to climate change are considered. The strategies of adaptation to climate change are, therefore, dependent on the roles of the system of innovation to provide support and create conditions, where farmers could implement adaptation practices to climate change.

1.7.2. Adaptation gaps and adaptive capacity of farmers

Agriculture in developing countries is rainfall dependent and vulnerable to recurrent droughts (Boko *et al.*, 2008). On another way, climate variability and change may increase the frequency of drought and thus reduce the coping range and adaptive capacity of the vulnerable population (IPCC, 2007). Coping and adaptation strategies ranges are breached under climate change if the ability to adapt is held constant. Vulnerability will increase to extreme levels for the dry threshold over time situating in to account sensitivity and exposure is uncontrolled. With changing climate, therefore, rainfall tends to reduce gradually and frequency of drought increases due to dry spells. This calls for urgent needs for adaptation.

The adaptation needs further stem from the challenges of sensitivity and vulnerability to climate change, together with farmers low levels of adaptive capacity (Adger *et al*, 2005; Mabe *et al.,* 2012). This low adaptive capacity is linked to low level of economic, demographic, health, education, infrastructure, governance and institutional capabilities (Vincent, 2015). Furthermore, the process of individual adaptation to climate change also requires building of the cognitive level and behavioral change towards adaptation (Grothmann & Patt, 2005). This results an adaptation gap which is the gap between the intended and actual adaptation needs. However, it is possible to expand the coping range through introducing novel and stable adaptation practices that could improve the adaptive capacity of the rural livelihoods. Thus innovations minimize the exposure and sensitivity of farming households to the changes and overall strengthen the farmers' adaptive capacity. Hence, innovative adaptation practices can reduce vulnerability of the exposed bio-physical systems in general, the rural population in particular with a consequent reduction in vulnerability (Thorlakson and Neufeldt, 2012; Zhang *et a*l., 2007).

1.7.3. Institutional Innovation needs in the agricultural sector to adapt to climate change

System of innovation in the agricultural sector is the systemic interactional processes that generate and hybridize different forms of knowledge (scientific, tacit, and local know-how) produced by multiple actors to solve multifaceted environmental and social problems of agriculture (Temple *et al.,* 2016; Bardaji *et al.,* 2009). In relation to the applications of the concept and scope of system of innovation in the agricultural sector, two approaches are contrasted (Touzard *et al.*, 2015). The first approach takes in to account a macro level analysis such as national system of innovation (NSI), which analyses the institutions or the regional system of innovation (RIS), analyses innovation at a regional level but common to all sectors. The second classification tends to the sectoral system of innovation (SSI), which is intended to analyze innovation of institutions, and networks promote the production of new knowledge in a specific sector (Malerba, 2002; Cooke and Morgan, 1994). This two approaches are however, needed to be coined by a system of construction and interaction. This deals how the interaction between different actors and institutions of different sectors is constructed (Carlsson, 2012).

1.8. Structure of the Thesis

The rest of the Thesis is structured as follows: Chapter 2 introduces the general methodological approach used in this Thesis. Primarily, description of the study area in general is presented. This comprises the geographical location and climate of the study area, socio-economic and farming typologies, and the institutional setups of the study area. Specific requirement for specific topics is presented on the specific studies or chapters in detail. This chapter is limited to the general overview of the background of the area. The second part of this chapter summarizes the overall methodological framework we used to select the study area, collect and analyze the data and present the results. This is the synthesis of the methodology in general, while the specific methodologies are presented in the separate studies. Chapter 3-5 presents the results and discussions of the Thesis, which are separated in to three studies (Study I-III). Study I (Chapter 3), presents how local people perceive climate change, its correspondence to stochastic analysis of historical climate data and the need to integrate farmers' perception with historical climate data to contribute to adaptation policy. Study II (Chapter 4), evaluates the response of farmers to current environmental and social changes and their perception of climatic variability, to define adaptation strategies to climate change. Farmers' behaviour is primarily due to lack of resources to adapt to changes in the market and climatic pressures. However, farmers that are aware of changes in climate are more willing to explore adaptation strategies though it is not the only determinant factor. This chapter, therefore, analyses the adaptation strategies implemented by farmers, the determinants of adaptation and the implications of adaptation of strategies to household income. Study III (Chapter 5), presents the role of institutions in the uptake of climate change adaptation innovations presenting a case from the coffee and dairy farmers in Central Kenya. Finally, Chapter 6 presents the synthesis of the findings and concluding remarks. This chapter, specifically summarizes the main findings and discussions of the three studies (Study I-Study III), the theoretical, and methodological contributions, and contributions to the learning, innovation and research, which collectively explained as contribution to the academia. Further implications to policy and development, and recommendations for further research are also presented.

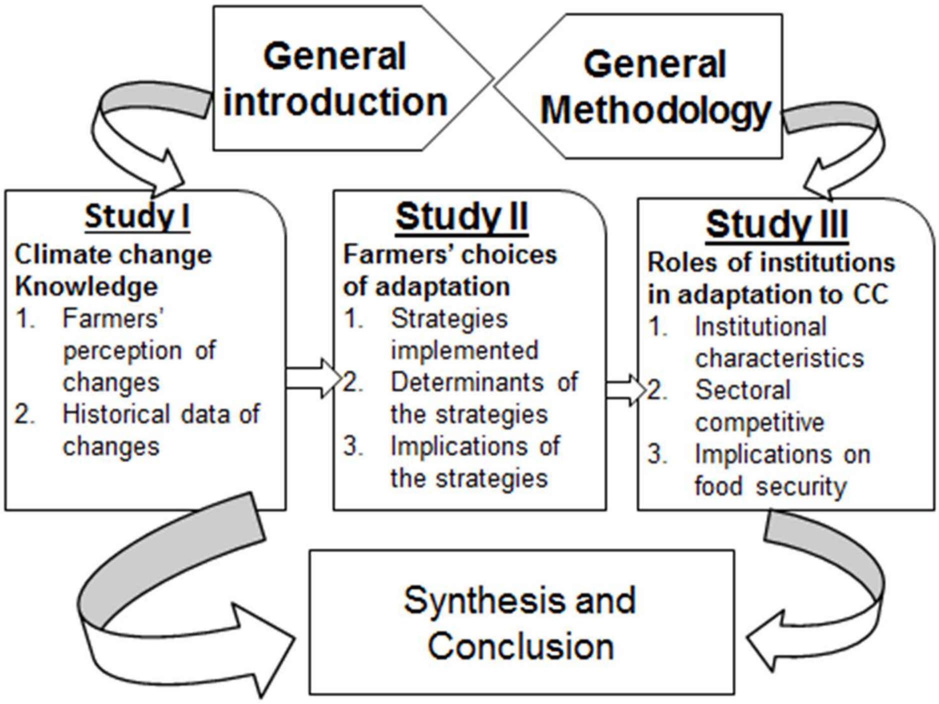


Figure 4 : General structure of the Thesis

1.9. Publications

The results of this Thesis are presented in three independent but consecutive studies (three chapters). These are presented in different oral and poster presentations of different conferences and submitted to different peer reviewed JCR journal. The first article is on process of review. The second article is in press for its format and content edition. The third article is accepted and it is now in its process of publication. The referential short form of articles published in journals are presented below. The papers presented in international workshops, seminars and conferences are presented in the appendix I, II and III.

Study I

Asayehegn, K., Iglesias, A., Pedelahore, P., Vaast, P., Temple, L., Triomphe, B., 2016. Farmers' perceptions of climate change and historical data: linking evidence to support adaptation policy in Central Kenya. Journal of Climate and Development.

Study II

Asayehegn, K., Temple, L., Sanchez B., Iglesias, A., 2016. Perception of climate change and farm level adaptation choices in central Kenya. In press, Cahier Agriculture.

Cahiers Agricultures *is an interdisciplinary forum on agronomic research and rural development. They are addressed to all those, researchers, field workers, teachers who want to conduct a more global reflection on the agricultural. It gives priority to research on agriculture as implemented by farmers, that has meaning for citizens in countries in the North and South, as opposed to research work conducted in a controlled environment (laboratory, research center, etc.). Research of this type is often multidisciplinary and takes into account the knowledge and know-how of the different stakeholders. The different parties are also actively involved in research, alongside the scientists. In this way, the journal stimulates debate on issues linked to society, such as the impact of using water and nitrogen fertilisers, peri-urban farming, fish farming, livestock production in rural areas, food security, etc. All articles are available free of charge, without publishing fees for authors. Cahiers Agricultures is indexed in the Scopus, Web of Science, Agricola (FAO), AGris, BOAJ and CAB Abstract.*

Study III

Asayehegn, K., Iglesias, A., Pedelahore, P., Triomphe, B., Temple, L., 2016. The role of institutions in the uptake of climate change adaptation innovations: a comparative study among coffee and dairy farmers in Central Kenya. In press, Journal of Innovation Economics and Management (I-JIEM).

Journal of Innovation Economics and Management (I-REMI) is co-edited by Research Network on Innovation (RRI) published and De Boeck University. It is distributed by the CAIRN portal. The Journal is indexed in the AERES (French Evaluation Agency for Research and Higer Education), the CNRS (French National Center for Scientific Research), the FNEGE (French National Fondation for Management Education) and EconLit

CHAPTER TWO
METHODOLOGICAL APPROACH

2. METHODOLOGY OF THE STUDY

2.1. Area of the study

This study was done in Murang'a County, one of the counties in Central Kenya with an average potential for agriculture. To describe the study area, and Kenya in general, in this case, we developed a framework which enables us to easily organize similar concepts under a common sub-themes or components. Our framework to present the background information consists of four major components (Figure 5), i.e., (1) geographical location and climate background, which includes the agroecological zone and weather phenomona of the study area, (2) socio-economic context of the study area contains descrpition of economic progress, poverty lvel and population related characterization of the study area, (3) farming systems undertaken by farmers of the area, and (4) institutional background of the coffee agroforestry in the study area which includes micro-finance institutions, meteorological stations, and extension and advisory services typically available in the study area.

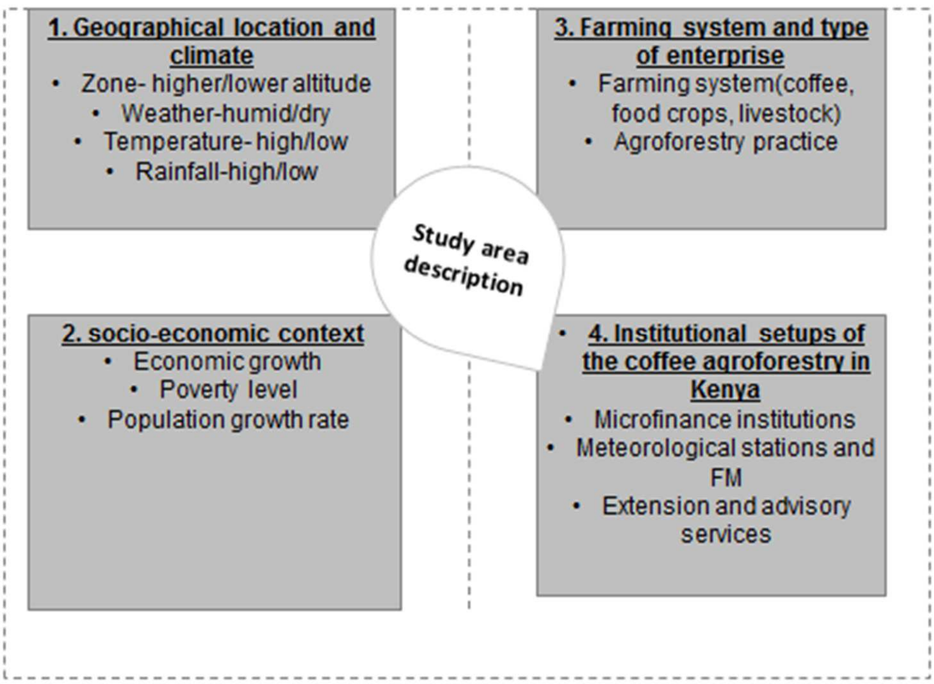


Figure 5: Framework to organize the criteria to describe the study area

2.1.1. Geographical location and climate of the study area

Kenya has climatic and ecological extremes with altitudes varying from sea level to over 5000 meters in the highlands. Out of the total area coverage of the country, approximately 85% is classified as arid and semi-arid land. The arid and semi-arid areas support almost 30% of the total national population and 70 % of the livestock production (Gov of Kenya, 2007). The semi-arid and arid lowlands have got attention and focus by different development and research organizations as a response to their vulnerability to climate change. However, the production potential highlands with less attention by development and research organizations are projected to suffer the most from a temperature increase of about 4 degrees, while the lowlands expect a 2-3 degree increase (steeg *et al.*, 2010).

Kenya has a warm and humid climate particularly the eastern coast which has an Indian Ocean weather, with wildlife-rich savannah grasslands inland towards the central and southern parts of the country (Figure, 6). The capital of the country, Nairobi has a cool climate that gets colder approaching to Mount Kenya (Figure 6). Further inland, there is a warm and humid climate around Lake Victoria, and temperate forested and hilly areas in the Western region. The Northeastern regions which is bordered to Somalia and Ethiopia are arid and semi-arid areas with difficult landscapes for farming. The area receives a great deal of sunshine every month. The mean annual rainfall ranges from less than 250mm in semi-arid and arid areas to nearly 1400mm in high potential areas. Generally, the country has two rains season with a different length and frequency. The "long rains" season, which occurs from March/April to May/June, where as the "short rains" season occurs from October to November/December. The rainfall is mostly erratic, sometimes heavy and drought hits in the other season. The temperature remains high throughout the months of tropical rain. The hottest period is February and March, leading into the season of the long rains, and the coldest is in July and August. Like many other African countries, Kenya depends on rain-fed agriculture for economic survival, which is highly vulnerable to the effects of climate change. Some of these effects which are already being seen in the area are: erratic rainfall, increased water scarcity, rising temperatures, and extreme weather events such as heat waves, floods and droughts. Decreases in agricultural production and environmental degradation as a result of climate change threaten the country's economy and its people's well-being (AFIDEP, 2012).

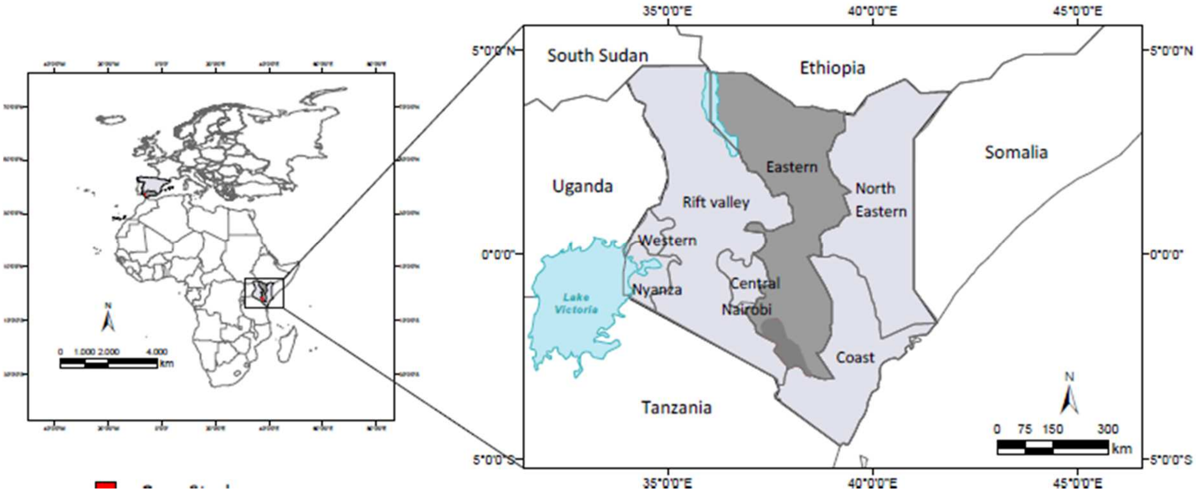


Figure 6: Map of Study Area

The particular study area, Murang'a County of Central Kenya, covers at least three agro ecologies (Figure 6), notably: - (1) the highland tea zone, which is the highest altitude area with potential to agriculture, (2) the mid-land potential coffee zone, and (3) the lower altitude lower potential area mostly used for food crops (Figure 7). The majorly emphasized part of this research, the coffee zone has also three categories, the intersection with tea, and the potential coffee and marginal coffee areas. The marginal coffee areas are places adjacent to the food crops, which was previously potential coffee zone, while the potential coffee zone is an area at the middle altitude between the marginal coffee zone and tea-coffee intersection (Figure 7). Altitudes higher to coffee zone are used for commercial tea production with some kind of mixing with coffee at the edge. The food crops zone on the other hand are places at the lower altitudes of the county and mostly used for staple food production (Figure 7).

There are two cropping seasons in the area, the long rain season, ranges from March to May with a higher monthly rainfall record in April and short rain season ranges from October to late November. Long rains are mainly used for long maturity crops such as hybrid maize varieties in the highland of coffee and tea zones while lower food crop zone uses only short maturity variety maize due to higher temperature and short rainy seasons.

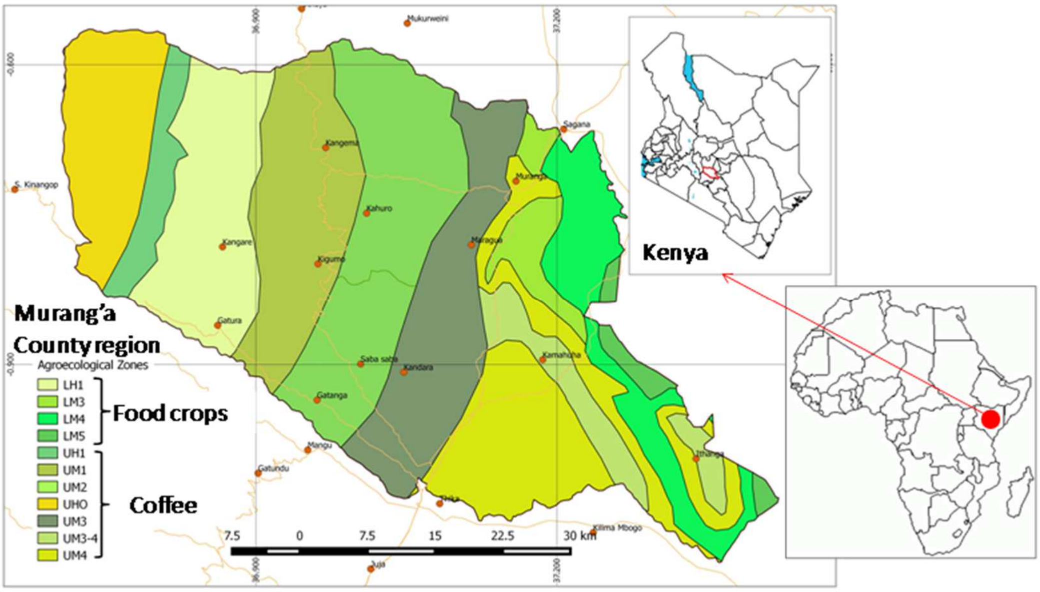


Figure 7: Map of study area

2.1.2. Socio-economic context

Kenya is one of the economically growing countries in eastern Africa. Since independence, the country's economy has grown slowly but steadily at 4.6% compounded annually with per capita GDP of $602.85 or $1.65 per day (WDI, 2006). This was the highest economic growth to the poor nations in east Africa. Poverty was however, still an increasing problem in Kenya, with the number of Kenyans classified as poor increasing from 29% of the population in the 1970s to 57% in 2000 (Library of Congress, 2007). Land holding size of small farm households is declined continued to higher population growth rate.

Coffee used to be an important cash crop and source of GDP, but it is significantly decreasing for the last three decades consecutively (appendix Table 2). This is evidenced by scholars for instance, Carsan *et al*., 2013, noted that intensive or reduced coffee production on smallholder farms around Mount Kenya threaten the conservation of valuable indigenous tree species. Not only the crop sector, but also the livestock sector is an important pathway for rural farm households to be out of poverty. For instance, globally, over 1 billion people depend on livestock, which provide power and manure for crop production, contribute to food and nutritional security, and are a form of savings for many poor people (FAO, 2009; McDermott *et al*., 2010; Rich *et al*., 2011). Livestock also make major contributions to the agricultural gross domestic product (GDP), export earnings and employment.

However, livestock production in the study area is declining from time to time. Besides their benefits, livestock are also responsible for adverse impacts on land, water, biodiversity and climate change (Steinfeld *et al*., 2006; FAO 2009). The competition for land and land resources grew in relation to the population growth. The population grew from about 5.4 million in 1948 to about 41 million in 2012. It is projected to reach 94 million by 2050 and more than 180 million by 2100 (UNFPA, 2012). The combined effects of climate change and rapid population growth are increasing food insecurity, environmental degradation and poverty levels.

2.1.3. Farming systems and types of enterprises

2.1.3.1. Agriculture

Agriculture including fishery and agroforestry is the mainstay of Kenya's economy, directly contributing 24 percent of the GDP annually valued at Kshs 342 billion (US$ 4.6 billion) and another 27 percent indirectly of GDP (valued at Kshs 385 billion equivalent to US$ 5.1 billion). The sector accounts for 65 percent of country's total exports with 50 percent of revenue and supports 18 percent of formal employment and more than 60 percent of informal employment in the country (Gov of Kenya, 2007).

Kenya's agricultural sector comprises six major sub-sectors. These include industrial crops, food crops, horticulture, livestock, fisheries and forestry. The principal cash crops are tea, horticultural produce, and coffee. Horticultural produce and tea are the main growth sectors and the two most valuable of all of Kenya's exports. Despite the central role that agriculture plays in the Kenyan economy, the sector continues to face productivity and land use challenges (Gov of Kenya, 2007). Yield and value over of crops are on the decline, for instance in 2005, total coffee production was

45,200 tones, of which 44 percent came from coffee estates with the balance 56 percent came from smallholder coffee farms. However, productivity in large estates was greater than in smallholder farms by a factor of 10 (KNBS, 2012). Agricultural productivity is constrained by a number of factors, including high cost of inputs (especially the price of fertilizer and seeds), poor livestock husbandry, erratic rains; limited extension services, over-dependence on rain-fed agriculture, lack of markets, and limited application of agricultural technology and innovation(ibid).

Particular to the study area, the main crops grown can be categorized as; cash crops, food crops and horticultural crops. Cash crops are mainly the industrial crops like tea, coffee and macadamia. Food crops are mainly grown for subsistence, while horticultural crops are largely for export market. Coffee production has been on the downward trend over the years due to poor prices at the international market. This has reduced tremendously the amount of fertilizers and agricultural chemicals being used by the farmers. Similar to the coffee production, yields of food crops have also been on a downward trend because of the high prices of agricultural inputs, erratic rainfall, warmer temperature and lack of supplemental irrigation. Farmers pointed out and prioritized twelve main challenges which are bottlenecks for their improving production (see Figure 8). Thus challenges differ due to the difference in agro-ecology and disparities in access to resources, assets and opportunities. Coffee farmers prioritize expensive farm inputs (fertilizer, pesticide, and improved seeds), erratic and insufficient rainfall, and shortage of financial capital as first, second and third major challenges in their farming, while food crop farmers of the lower altitude prioritize increase in temperature coupled with insufficient and erratic rainfall causing crops to fail before maturity, and lack of access to water for irrigation and irrigation technology to supplement their rain-fed farming (Figure 8). Expensive labor, expensive farm inputs and poor market are prioritize as major challenges by farmers with bigger farm size while shortage of financial capital, erratic rainfall and hot temperatures are prioritize by smallholders affecting them for intensive farming (Figure 8).

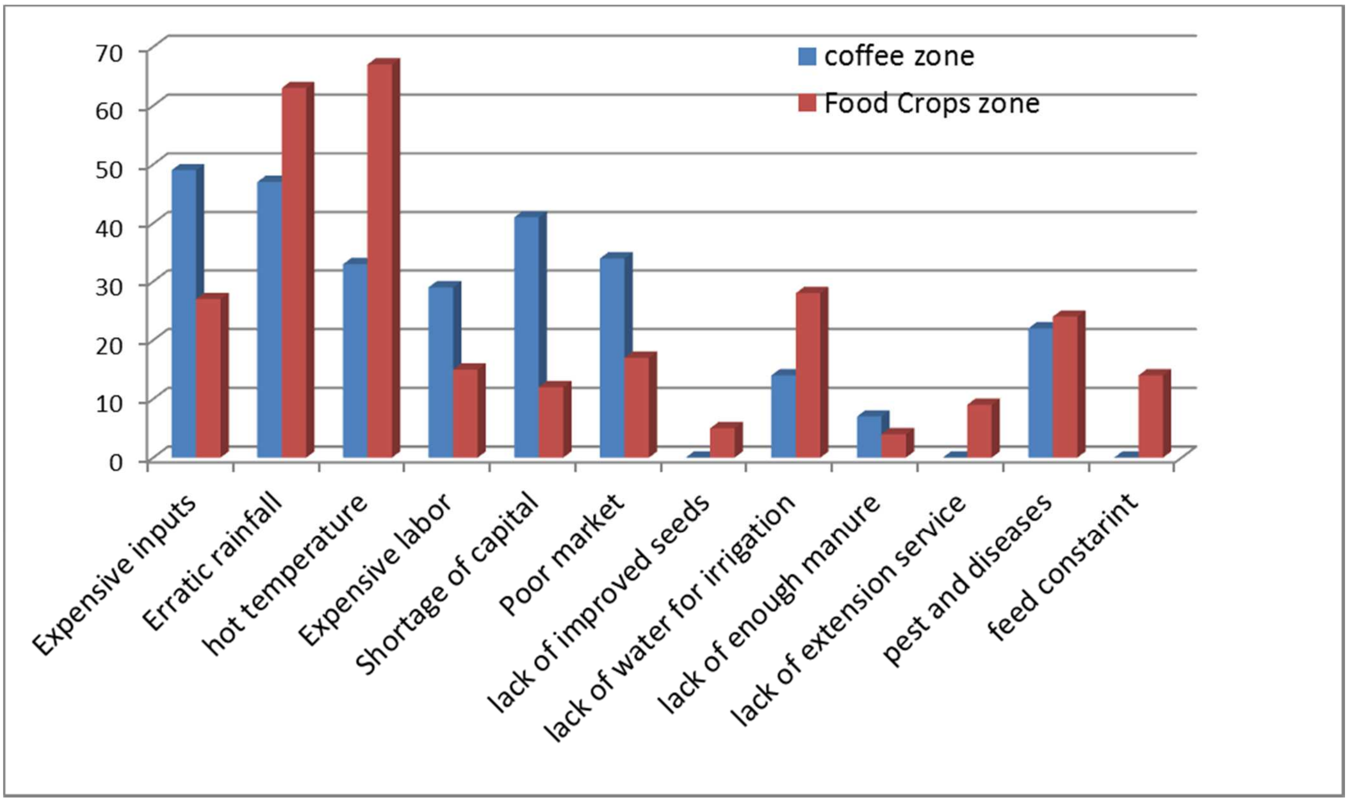


Figure 8: Major challenges facing farmers of Murang'a County

Source: Author's survey data, 2014

2.1.3.2. Agroforestry Diversity and Practice

The study area covers two zones of Murang'a County of central Kenya. The food crops zone subject to altitudes between 1100 through 1450 meters above sea level (masl) and coffee zone covers altitudes between 1450 through 1800 meters above sea level (masl). Food crop zone is conquered by crops such as beans, banana, maize, and dairy while coffee is dominant crop at the coffee zone with some combined tea and coffee farms at the margin from the higher altitude and food crops and coffee at the lower margin of the coffee zone. In both zones, it is common to find different trees with edible and non-edible fruits. Some of the edible fruit trees, which are common in both zones are macadamia, avocado, mango, banana, guava, e.t.c, while trees such as gravellia, eucalyptus, are dominantly used for firewood and construction. Grass, which are common feed for livestock such as Kikiyu grass, Napier grass are also common in the agroforestry system of the study area.

The impact of climate change, defined by decline in rainfall and increase in temperature differs between the two agro-ecological zones. The coffee zone is comparatively cooler with longer rain season than the food crops zone. But in general, there are two cropping seasons in both zones; the long rain season, ranges from March to May with a higher monthly rainfall record in April and short rain season ranges from October to late November. Long rains are mainly used for long maturity crops in the coffee zone while lower food crop zone farmers uses only short maturity varieties of maize due to higher temperature and short rain of the second season.

Central Kenya is the most populous and potential for agriculture where coffee farming has been the backbone of most rural highland economies (Carsan et al. 2014a). Coffee production is however, in a continuous declining trend for the last three decades. Countrywide annual production has declined from 140,000 metric tonnes in 1987 and stagnated at 50,000 metric tonnes and exports fell from 2.1 million bags in 1987 to 0.9 in 2007(Thuku, 2013). World market share has declined from 3.2% in 1987 to 0.6% in 2006 (Mude, 2006). In the potential coffee area of Murang’a County, the decline in production and coffee quality is severing. Coffee has extinct from the lower altitudes of the former coffee zone. High infestation of Coffee Leaf Rust (CLR) and Coffee Berry Diseases (CBD) are among the top reasons for the decline of production at the higher altitude and shifting from coffee to food crops at the lower altitude. (2) Most of the location specific adaptation studies (for instance Deressa, 2008) are limited to annual crops production rather than the ecology dependent perennial crops like coffee.

2.1.4. Institutional setups

2.1.4.1. Meteorological stations

At national level, the Kenyan Meteorological Department (KDM) is the responsible organization to record, analyze, document, and dissemination of information on rainfall and temperature. The department is responsible to inform the stakeholders about the onset and cessation of rainfall, temperature conditions, and the probability of drought, which supports the stakeholders to develop the system of early warning and prepare for the response.

The climate outlook particular to rainfall in the department considers two seasons, i.e., the short rain season and long rain season rainfall. The short rain, for the October-November-December and long rain, for March—April-May is analyzed at daily, weekly, bi-weekly, monthly and annual analysis. Analysis from 2016 and 2015, for the short and long rains, for instance, indicated that much of the country was experienced generally depressed rainfall that was mainly driven by the evolving La Niña conditions in the eastern and central equatorial Pacific Ocean and cooler than average Sea Surface Temperatures (SSTs) over the western Equatorial Indian Ocean (adjacent to the East African coastline) and warmer than average SSTs over the eastern Equatorial Indian Ocean (adjacent to Australia) that constitute a negative Indian Ocean Dipole (IOD) (source, department outlook report, 2016). For the June, July and August period, most parts of the country experienced generally sunny and dry weather conditions.

The meteorological stations were installed at different areas of the country. Country wide, a total of 36 weather observing stations, 10 hydrological stations, and 4 marine stations were installed and networked until 2014 (KDM, 2016). These were the stations which were networked and with continuous reliable data for more than 10 years. In Murang'a County, for instance, different stations were installed during the colonial time. Most of them were, however, outdated, and closed due to different reasons, such as poor management from the offices. Some were not networked with the system and have difficulties to retrieve the data consistently and effectively. Recently, the department started to revive some of the stations and install new once at places which can represent different agro-ecologies. The stations in Murang'a County which were in full service for at least one element of climate during 2013/4 are presented in Figure 9 bellow.

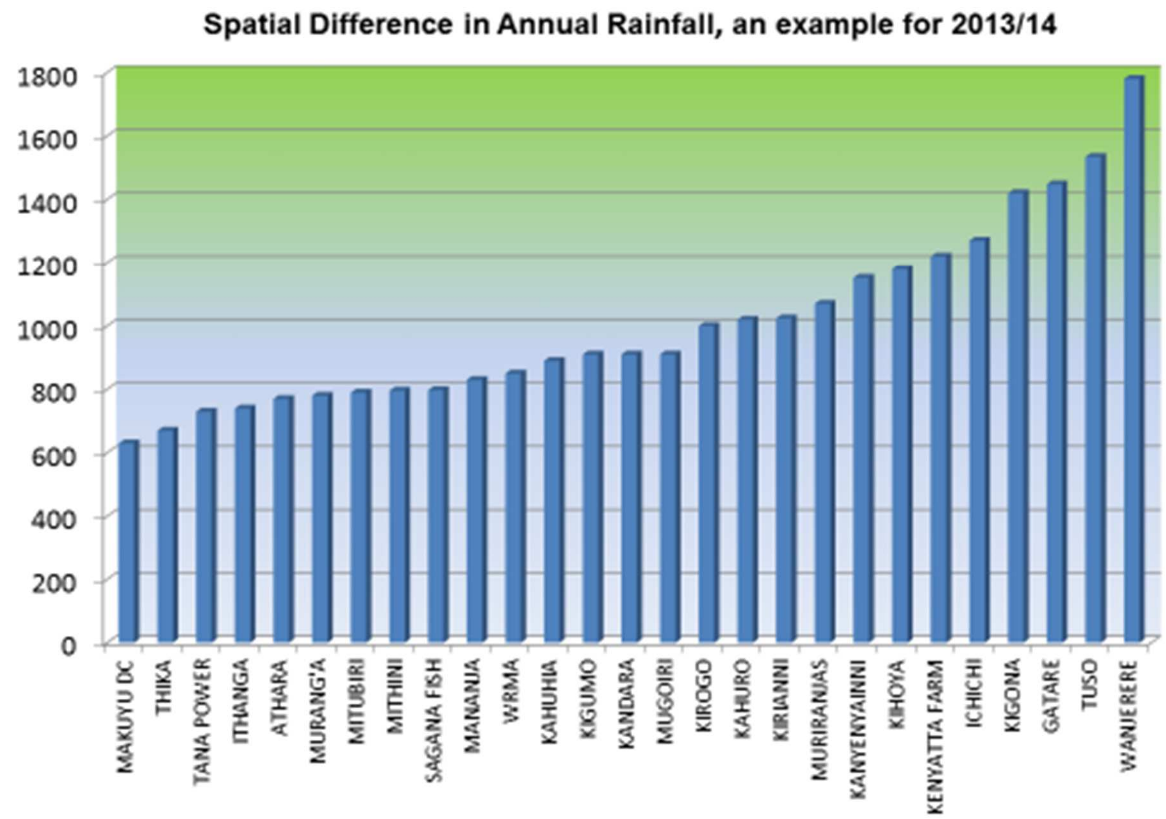


Figure 9 : Meteorological stations in Murang'a County in 2013/14

Source: KDM, 2014

2.1.4.2. Extension, advisory services and microfinance

Agricultural extension in Kenya dates back to the early 1900s, but its only notable success was in the dissemination of hybrid maize technology in the late 1960s and early 1970s. The Ministry of Agriculture and Rural Development formulated the National Agricultural Extension Policy (NEAP) established in 2001 to guide improvements in delivery of extension services. The NEAP recognized the need to diversify, decentralize and strengthen the provision of extension services to increase their sustainability and relevance to farmers.

Currently, the extension system and advisory services have three way of delivery services: the public sector, the private non-profit sector and the private for-profit sector. The public sector institutions includes Ministries and departments of Agriculture and Agricultural Research Centers. The private non-profit sector includes local and international NGOs, foundations, community based organizations, farmers federations, and associations. Some other non-government organizations which are based in Kenya and contributing the advisory services are World Agroforestry Center (ICRAF), ICIPE, CYMMIT, CIP ICRISAT and IITA. The details of the institutions and organizations are presented in Study III.

Generally, micro-finance institutions provides financial services to the low-income households and micro and small enterprises (MSEs), which provide an enormous potential to support the economic activities of the poor and thus contribute to poverty alleviation. Among the major micro-finance institutions in Kenya are the private banks, farmers' cooperatives, unions and federations, share companies and independently established companies. Widespread experiences and research have shown the importance of savings and credit facilities for the poor and MSEs. This puts emphasis on the sound development of microfinance institutions as vital ingredients for investment, employment and economic growth. Particular to the study area, Murang'a Coffee Union and cooperative, Dairy cooperatives, cereal crop and horticultural cooperatives, self-help groups, government and private banks, provide different types of credit at different level of interest rate and collateral.

2.2. Framework, Data and Methods

2.2.1. Framework

This study is structured in three consecutive and interlinked studies (study I-III). Data collection, target group and target methodologies differ from one chapter to another chapter (Figure 10). This covers the adaptation strategies to climate change from three perspectives-: 1) farmers' knowledge and perception of climate change, 2) farmers' practical and technical implementation of adaptation strategies, and, 3) the systems of innovation, which comprises different actors and their interaction and the institutional dimension to support adaptation to climate change.

Study I, covers the objective to assess the farmers' perception towards climate change in terms of climate parameters, such as temperature and rainfall. It also characterizes farmers in terms patterns both spatially and temporally. Analysis of historical climate data which was collected from the meteorological stations of the study area was also part of this chapter. Finally, this chapter compares farmers perceptions of climate change with the historical climate data collected from Meteorological stations. The trend analysis was done using a nonparametric test of Mann-Kendall test and Sen's slop estimator to understand statistical significance (see Figure 10).

Study II, evaluates the adaptation strategies implemented by food crops and coffee farmers of the study area. This includes the types of adaptation strategies common to the area, prioritization of the choices by farm households, determinants of the adaptation strategies and their implication to household income. This comparison was done using Heckman's two stage estimation to analyze farmers' choices of adaptation strategies at the first stage, and their marginal effect on the second stage (see Figure 10).

Study III explores the roles of systems of innovation to bring new frontier of adaptation to climate change, comparing evidences from coffee and dairy sectors. In this article, we mobilized the sectoral systems of innovation framework due to different reasons. First, the study compares coffee and dairy sectors which are similar in terms of farmers' objectives and shifting historical fortunes, but are different in terms of marketing, socio-political and technical characteristics and policy. Second, the interest to contribute to the sectoral system of innovation literature from the sectors other than industrial. And third, to bring an insight on the sectoral differences in adaptation to climate change. Basically, this chapter provided an answer to the questions such as: - what characteristics of the systems of innovation are particular to each sector in the adaptation process to climate change? how these characteristics of the innovation affect the adaptation process and competitiveness of the sectors? How do different actors in the innovation system of the coffee and dairy sectors of the study area (the development institutions, research institutions and educational institutions) interact to designing the objective of climate change adaptation.

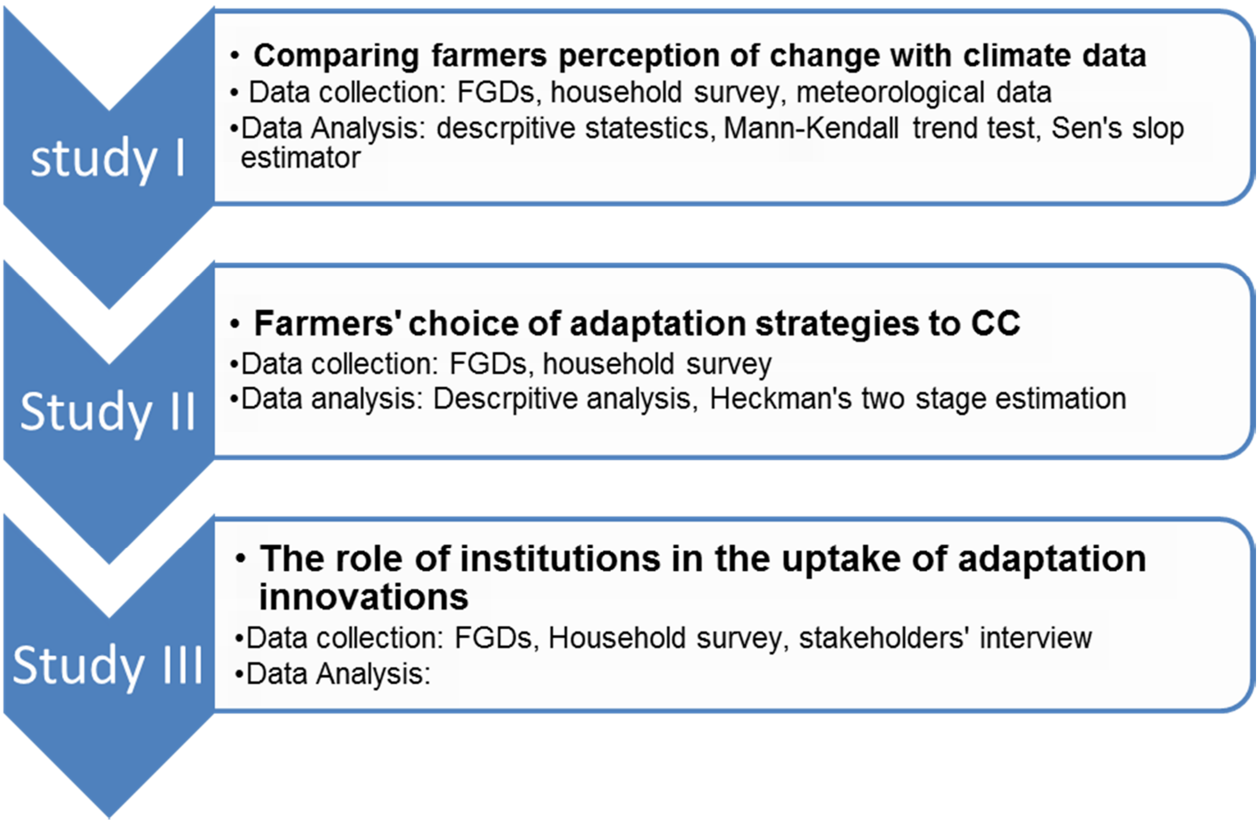


Figure 10: Proposed framework for collecting and analyzing data

2.2.2. Sampling design and data

Data collection for this study was done in two periods. The first period was during May-November, 2014, and the second period was during May-October, 2015. Four types of data were collected from different sources during this study in order to understand the adaptation strategies and determinants to climate change from different actors, i.e., (1) household data, (2) historical climate data, and (3) stakeholders' data.

A wide range of approaches were used to collect the data. These approaches include household surveys, Focus Group Discussions, stakeholders' interview, reviewing and synthesis of case studies, and public database such as meteorological data of temperature from Kenya Meteorological department (KMD). The household data comprises :- (1) farmers' Focus Group Discussion in general (FGDs) (Appendix Table 7 and 10), (2) household interview with coffee farmers (Appendix Table 8), (3) household interview with food crops farmers (Appendix Table 9), stakeholders interview with different actors, such as cooperative, research institutes, government officials, financial institutions, development organizations, community based organizations (Appendix Table 10). The sample of household data for Study I and II was consisted of 220 farm households equally stratified to coffee farmers (110 surveys in the coffee area) and food crop farmers (110 surveys in the food crops area of the county). For Study III, the sample household survey consisted of 240 household heads (86 coffee specialized, 102 coffee-dairy diversified, and 52 dairy specialized farmers). The household survey data of the three studies was supported by data from Focus Group Discussions (FGDs) of different number of groups and group size for the different studies.

Focus group members were selected by local leaders after we developed different criteria for selection, such as length of farming experience, extent of knowledge about the village and ability to retrieve and express long term stories about the study area. The selection of FGD participants also considered the inclusion of different age groups, wealth category (better-off, middle and poor farmers), farming practices and gender. The aim of the FGDs was to understand the community wide problems and generate information on agricultural practices and perception of climate change. It helped us also to ensure if the surveys were well worded and relevant. Consequently, we modified the survey questionnaire based on the results of the FGDs. Representatives from different institutions and stakeholders were also part of the sample for this study. Detail explanation and description on the targets and samples, methodology followed to choose for each chapter is presented on the specific chapters (Study I-III)

2.2.3. Analytical methods

2.2.3.1. Descriptive analysis

This study combines qualitative and quantitative analysis. Description of contexts, characterizing and narratives of qualitative data was among the repeatedly used qualitative methods in this study. In addition to the qualitative narratives, statistical analysis, such as mean, percentage, frequency were used. These analytical results were presented in absolute figures or diagrams.

2.2.3.2. Model analysis

Two model analysis used in this Thesis. The farmers' perception of long term climate change was compared with measured historical climate data of temperature, and rainfall to understand, whether the two sources of information on climate change are consistent. A simple flowchart framework was developed for organizing the farmers' qualitative views of climate change, while nonparametric Mann-Kendall test was used to determine trend analysis of rainfall and temperature. This helped us to understand the trends observing at the statistical significance and Sen's slop estimator, which evaluates the direction and magnitude of the trends. A positive slop in Mann-Kendall test indicates an increase in the climatic parameter, while a negative slop proves a decrease.

Second a model analysis for adaptation choices was used. Decision making depends on availability of choices. In the area of climate change adaptation innovations, which satisfies this assumption, farmers may be unable to adopt their most preferred innovation due to uncertainty in the realization of choices as a result of different drivers. Empirical studies, such as Abid *et al.,* (2015) and Bryan *et al.,* (2013), used a binary logit regression to measure adoption choices by classifying the dependent variable in to binary option as adopted choices and not adopted. Farmers, however, differ in choices of adopting the strategies (some adopts single choice, while others adopt multiple of choices). Applying binary logistic regression is inappropriate to evaluate, if adoption of combination of adaptation choices is better over the adoption of single choices. We, therefore, used Heckman's two stage estimation model to first model the adaptation strategies, the factors affecting adoption of adaptation strategies, and then evaluate the implications of every adaptation strategies. The parameter estimates of the MNL model explains how citrus paribus changes in the elements of x affect the response probabilities, while the marginal effects or probabilities measure the expected change in probability of a particular choice being made by a farmer with respect to a unit change in an explanatory variable from the mean, and is a function of the probability itself. The details and model specifications are presented on the specific chapters.

Chapter Three

Farmers' Perceptions Of Climate Change And Historical Data: Linking Evidence To Support Adaptation Policy In Central Kenya

3. FARMERS' PERCEPTIONS OF CLIMATE CHANGE AND HISTORICAL DATA: LINKING EVIDENCE TO SUPPORT ADAPTATION POLICY IN CENTRAL KENYA

Kinfe Asayehegn, Ana Iglesias, Philippe Pedelahore, Philippe Vaast, Ludovic Temple, Bernard Triomphe

Abstract

This study assesses how local people perceive climate change, its correspondence to stochastic analysis of historical climate data and need to integrate the perceptions with climate data to contribute to adaptation policy. The data collection involved three sources of information (1) eight Focus Group Discussions to define the collective perception, (2) 220 household surveys, and (3) the historical climate data from Central Kenya. The data analysis included: (1) characterizing climate changes as perceived by farmers; (2) identifying climate change patterns from historical records; (3) comparing farmers' perception with the historical climate data to assess consistency and potential for integration to support to adaptation policy. The results show the farmers' perceptions of temperature change were consistent with the historical trends for both food crops and coffee zones, while no evidence in rainfall records found to support farmers' perceptions of decreasing rainfall at the food crops. Farmers' perceptions and historical trend analysis are consistent, however, on rainfall patterns. This consistency (discrepancy) determines adaptation policy. Farmers prefer to bring changes in agronomic practices and diversify income sources, while policy actors prefer macro level long term investment strategies. An integrated interpretation taking into account both knowledge sources to identify adaptation needs could better support locally-adapted policy.

Keywords: Farmers' perception; historical climate data; rainfall; temperature; Central Kenya

Résume

Cette étude évalue la façon dont les populations locales perçoivent le changement climatique, sa correspondance à l'analyse stochastique des données climatiques historiques et recommande d'intégrer les perceptions avec les données climatiques pour améliorer politiques d'adaptation au changement climatique. La collecte des données se base sur trois sources d'information (1) huit groupes de discussions ont permis de définir la perception collective, (2) 220 enquêtes ménages, et (3) les données climatiques historiques au Kenya Central. L'analyse de données inclus: (1) la caractérisation des changements climatiques tels qu'ils sont perçus par les agriculteurs; (2) l'identification des modèles de changement climatique à partir des données historiques; (3) la comparaison de la perception des agriculteurs avec les données climatiques historiques afin d'évaluer la cohérence entre ces deux éléments et le potentiel que cette analyse représente pour appuyer le développement de politiques d'adaptation. Les résultats montrent que les perceptions des agriculteurs sur le changement de température sont conformes aux tendances historiques pour les cultures vivrières et les zones de production de café alors que les données pluviométriques ne corroborent pas les perceptions des agriculteurs de baisse des précipitations sur les cultures vivrières. Les perceptions des agriculteurs et l'analyse des tendances historiques sont cependant cohérentes avec le régime des précipitations. Cette cohérence (écart) détermine la politique d'adaptation. Les agriculteurs préfèrent changer leurs pratiques agronomiques et diversifier les sources de revenus alors que les décideurs politiques préfèrent employer des stratégies d'investissement à long terme au niveau macro. Une interprétation intégrée prenant en compte les deux sources de connaissances pour identifier les besoins d'adaptation permettrait de mieux appuyer le développement d’une politique locale adaptée.

Mots-clés: perception des agriculteurs ; données climatiques historiques ; precipitations ; temperature ; Kenya Central

Resumen

Este estudio evalúa cómo la población local en la zona central de Kenia, percibe el cambio climático, su correspondencia con el análisis estocástico de los datos climáticos históricos y la necesidad de integrar las percepciones con los datos climáticos para contribuir a la política de adaptación. La recopilación de datos incluyó tres fuentes de información: (1) ocho discusiones de grupos focales para definir la percepción colectiva, (2) 220 encuestas de hogares y (3) los datos climáticos históricos de Kenia Central. El análisis de los datos incluyó: (1) la caracterización de los cambios climáticos percibidos por los agricultores; (2) identificación de patrones de cambio climático a partir de registros históricos; (3) comparar la percepción de los agricultores con los datos climáticos históricos para evaluar la coherencia y el potencial de integración para apoyar la política de adaptación. Los resultados muestran que las percepciones de los agricultores sobre el cambio de temperatura son consistentes con las tendencias históricas tanto para los cultivos alimentarios como para las zonas cafetaleras, mientras que no hay evidencia en los registros de lluvia que apoyen la percepción de los agricultores de la disminución de las precipitaciones en los cultivos alimentarios. Sin embargo, las percepciones de los agricultores y el análisis de las tendencias históricas son consistentes con los patrones de lluvia. Esta consistencia (discrepancia) determina la política de adaptación. Los agricultores prefieren introducir cambios en las prácticas agronómicas y diversificar las fuentes de ingresos, mientras que los actores políticos prefieren las estrategias macroeconómicas a largo plazo. Una interpretación integrada que tenga en cuenta las dos fuentes de conocimiento para identificar las necesidades de adaptación podría apoyar mejor la política adaptada localmente.

Palabras clave: Percepción de los agricultores; Datos climáticos históricos; lluvia; temperatura; Kenia central

3.1. Introduction

The Intergovernmental Panel on Climate Change (IPCC's) Fifth Assessment Report (AR5) provides undisputable evidence of climate change driven by the increase in global greenhouse gas emissions (GHG) (IPCC, 2014). Global GHG emissions have grown since pre-industrial times, with a sharp increase of 70% between 1970 and 2004. This caused minimum and maximum temperatures to increase globally, and particularly in the tropics (IPCC, 2013). Africa is considered as one of the most vulnerable areas to climate change (Rosell and Holmer, 2007). The change and distribution of temperature in the region varies with altitudes and micro-climate but in average, temperature of the hottest months has increased by more than 2°C (Anyah and Qiu, 2012). Rainfall for its part experienced both a high degree of variability and a declining trend over the last 60 years (Rosell and Holmer, 2007), while rainfall patterns (such as onset, duration, cessation) have changed and intermittent dry spells have caused critical soil moisture decline (Dhanya & Ramachandran, 2015).

Due to the direct relationship between crop production and climate, agriculture is the sector most affected by climate change (Howden *et al*., 2007; Molua, 2006; Angeon and Bates, 2015). As temperature and rainfall patterns are expected to continue to change, impacts will be severe (Bardaji & Iraizoz, 2014; IPCC, 2014). Rainfed crops may decrease productivity by up to 50 percent globally in the next two decades (IPCC 2014). The impact of climate change is higher in Africa, its food production systems are among the most vulnerable due to its extensive reliance on rainfed crops production, recurrent droughts and high variability in climate (Boko *et al.* 2008). This comprises decline in yield of major crops (Lobell et.al., 2008; Liu *et al.* 2008), decrease in quality of livestock products and loss of livestock herd size due to feed shortage (Jones & Thornton 2009), limit opportunities to diversify household livelihoods (Bernstein *et al*. 2007).

Policy decisions to adapt to the changing climate need to take into account the rate of climate change observed in the past, as well as current and future trends which reinforces new infrastructural development to be responsive to the changes (Hallegatte, 2009). Climatologists have developed different methodologies to analyze and understand the rate of changes in climate, particularly through the uses of predictive models. The future climate trends are however, uncertain, and hence direct use of the outputs of existing climate models (single information source) developed by scientists may well be insufficient to guide the development of adaptation policies. It would seem wiser to take in to account other sources of information about climate change to develop adaptation policies (Hallegatte, 2009).

Due to their long-lasting association to their environment, local people have generated a wealth of environmental knowledge and the changes such environment undergo over time such as climate change via direct experience and inter-generational transfer (Armah *et al*, 2015; Molua, 2014: Opiyo *et al*, 2015). Furthermore, farmers constantly adapt their production practices to climate change as they perceive it, without waiting on the adaptation policies being currently developed by governments and formal R&D institutions (Brody *et al*, 2008; Comoé *et al*., 2014). Such local knowledge of changes and experience with climate change adaptation on the ground has not yet been much taken into account for developing formal climate change adaptation policies (Comoé *et al.* 2014; Simelton *et al.* 2013; Kemausour *et al.,* 2011). The failure to consider farmers' knowledge and experience in climate change adaptation may increase the risk of maladaptation of public climate change adaptation policies (Jones *et al*. 2016). There is an active debate among scientists about such issues, with some believing farmers' knowledge of climate change is pivotal for policy decisions while others disregard it (Armah *et al.* 2015).

Among those who tend to disregard farmers' knowledge, Mugalavai *et al*, (2008); Weber (2006); Blennow *et al*. (2012) consider climate change as basically probabilistic and often regard it as an issue that is beyond human perception. Farmers' cognition and social institutions are considered of little value (Rodima-Taylor *et al*. 2012) while the stochastic analysis of historical climate data is considered as the only inputs necessary for adaptation policies and decisions (Kemausuor *et al*. 2011; Chaudhary and Bawa 2011).

Among those who value farmers' knowledge, Jones & Tanner (2016), Burnham and Ma (2015), García de Jalón *et al.* (2013) documented experiences from different countries and contended that not every adaptation decision requires consideration of long-term historical climate information for a successful outcome to be achieved. Rather they claim that valorizing of local people's knowledge could bring out better results. For them, climate change research should emphasize on the importance of location specific, lifelong experience based cognitive evidence (Armah *et al.* 2015). They regard adaptation as being location-specific and essentially demanding behavioral and attitudinal change on the part of local people. In this regard, farmers' perceptions are likely to be important and therefore useful to individuals for responding to changes.

These two approaches are neither mutually exclusive nor self-exhaustive, but may be considered as complementary. This is particularly the case in locations where temperature and rainfall records may be unreliable or unavailable (a situation common to most East African Countries) and for which using a pure statistical analysis to determine climate change would be haphazard. For instance, climate change scenarios and models are unanimously projecting an increase in future ground temperature in Eastern Africa. There are however inconsistencies regarding changes in rainfall, with some studies projecting an increase (Haarsma *et al*. 2005) while others project a decrease (Castellanos *et al*. 2012). Shilenje & Ogwang (2015) reported that unreliable regional climate records and poor management of existing meteorological stations contribute to unreliable data results. Perception on the other hand, is linked to farmers' action (Brody *et al*, 2008) and be hinder by impacts than the actual changes. Analysis of perception for longer time period could however be distorted by recall bias (Hahn *et al*, 2009) and hence could yield unreliable climate policies and adaptation needs (Armah *et al.* 2015). Understanding changes both from local perceptions and from historical data is, therefore, fundamental to both climate science and adaptation policy formulation because it tackles local and global contexts where scientists and policy actors operate (Burch and Robinson, 2007).

Studies considering the integration of farmers' perception and historical climate data in East African context are scant (Armah *et al*, 2015; Mwalusepo *et al*, 2015). Hence, the objective of this study is to contribute to an understanding of how farmers perceive climate change and how such perceptions compare with the locally available historical climate data in Murang'a County in central Kenya in which coffee production has been declining over recent decades. The changes in Murang'a are typical example of changes experienced across much of Eastern Africa. Farming and land use systems of the area have been changing, moving from being a major coffee-producing area to mixed farming systems including food crops (Barjolle *et al,* 2013; Anon, 2013). One of the hypotheses for explaining such change is that it reflects the impact and perception of climate change.

In this study, we used a combined approach, focusing on the complementarity of farmers' views and historically measured data. Farmers' perceptions were based on households' data about their views while the measured change used historical data of temperature and rainfall from representative meteorological stations. Trend analysis was performed using Mann-Kendall test and Sen's slop estimator. In the next section, we present the study region. We then give an overview of the methodology used to collect and analyze data and finally we present the results and discussions.

3.2. Data and methods

3.2.1. Profile of the study area

There are two cropping seasons in the area: (1) the long rain season ranges from March to May with highest rainfall recorded in April and (2) the short rain season ranges from October to late November. The area is made up of three agro-ecological zones each corresponding to a different altitude range (high, mid and low altitude), and characterized by a specific climate and weather: cold temperature and higher rainfall in the highlands, hotter temperature and lower rainfall in the lowlands) (Table 1). Associated with such climate features, crops differ according to the agroecological zone: tea and Coffee are the main crops at the higher and mid altitude areas respectively, while food crops (maize and beans) dominate in the lowlands.

Table 1: Main features of the agroecological and cropping systems in Murang'a, Central Kenya

Zone	Altitude range (masl)	Main cropping system and agroecological characteristics
Coffee-tea intersection	Before[1]: 1650-1950 Present[1]: 1850-2000	• coffee and tea shares the cropping system equally • relatively cold temperatures and higher rainfall • longer rain season with late onset and cessation • relatively bigger farm size
Main coffee	Before: 1340-1680 Present: 1600-1800	• More than 80 % of the cropping system is dominantly coffee • Other crops are beans and maize • Relatively higher temperatures and lower rainfall, less absolute onset and cessation compare to coffee-tea zone • Small farm size
Marginal coffee	Before: 1300-1450 Present: 1400-1600	• coffee is gradually losing out to food crops such as maize, banana and beans • Hot temperatures and low rainfall
Food crops	Before: < 1300 Present : < 1450	• food crop(beans and maize) and some commercial crops(banana) • arid and semi-arid weather with high probability and frequency of crop failure • small farm size

[1]"before" represents the altitude coverage 35 years ago; "present" represents the current coverage at the time of data collection (2014).
Source: Authors own grouping of information

Over the last 35 years, coffee "moved up": whereas it used to be grown with good results at altitudes as low as 1300 masl, it is now grown at altitudes above 1600 masl (Table 1), while food crops are grown at the altitude once reserved for coffee production. Annual production and share of coffee in the County's GDP have significantly declined. Climate change is one of the major factors affecting coffee production: it induces the coffee trees to dry, increases the incidence of coffee pests and diseases (Jaramillo *et al.* 2013), depresses tree growth and provokes coffee flower abortion (Thuku 2013). Future projections (Laderach *et al*. 2011) indicate the optimum coffee-producing zone will shift still higher to the 1680-1800 masl range to compensate for expected temperature increase in the lower altitude ranges (Craparo *et al.* 2015; Laderach 2011).

3.2.2. Data sources

Survey data

Two types of data were collected for this study, i.e., 1) village and household data collected from the farming communities by means of eight Focus Group Discussions (FGDs) and 220 household surveys (110 farmers from each coffee and food crops zones) and 2) long-term meteorological data of temperature and rainfall.

The FGDs were conducted with about twelve farmers per group in each of the main four growing zones explained in Table 1 (two FGDs per zone). FGD members were selected by local leaders after we developed different criteria such as farming experience, extent of knowledge about the village and ability to retrieve and express long term stories about the study area. The selection of FGD participants also considered the inclusion of different age groups, wealth category (better-off, middle and poor farmers), diversity of farming practices and gender. An equal number of participants were therefore drawn from all categories. The aim of the FGDs was to understand the community wide problems and generate information on agricultural practices and perception of climate change. It also helped us to reformulate the household survey questionnaire.

For selecting representative farmers to participate in the household survey (interview), we used the farmers list in the agricultural office of the sub counties of all the communities. We first stratified our sample proportionally to the zones. We then took random selection to get the first farmer from the list and then we calculated the sampling unit for a complete list of sample farmers. The household survey was conducted via face to face interview during June-October 2014 with heads of households.

The FGDs was guided by semi-structured checklists while the household interview contained 24 questions in total including check-all and forced-choice questions followed by a comprehensive discussion with the farmers. The questions focused on five themes: (1) climate and climate change information and weather forecast; (2) farmers' perception of climate change in general; (3) farmers' perception of rainfall patterns, (4) farmers' perception of temperature patterns, (5) farmers' perception of climate change effects and impacts. The questions related to the general climate change perception and to climate change impact/effect were open ended while the specific questions related to temperature and rainfall were organized with sequential options ranged from strongly agree (value of 3) to strongly disagree (value of 0). Answers were coded in to different actual values.

Historical Meteorological data

Historical meteorological record of temperature (daily minimum and maximum) and rainfall (daily mean rainfall) over 35 years (1981-2014) from representative stations at the high and low altitude was retrieved from the Kenya Meteorological Department (KMD). Initially, an inventory of all the meteorological stations available in the County was done, yielding 21 stations. We then screened stations with reliable and sufficient data. Data quality was checked analyzing missing values and out of range data. Reliability of the data was set to be 95%. Meteorological stations which did not fulfill the reliability requirement or had only too short data sequences to allow trend analysis were rejected. Nine stations that represent the high, mid and lower altitude of the county were finally selected. Daily minimum and maximum temperatures were computed to get mean annual minimum, mean annual maximum and mean difference temperatures while daily rainfall measures were computed to annual rainfall measures.

3.2.3. Analytical methods

Analysis of farmers' perception of climate change

Farmers' perception of temperature and rainfall including patterns (onset, duration, cessation, intensity and inter annual variability) were characterized to compare the situation prevailing three decades ago with the current situation. To analyse such patterns, we adapted a simple flowchart matrix framework previously developed by Simelton *et al*.(2013) to organize the quotes on rainfall and temperature patterns flowing from left to right (Figure 11). The first level of the analysis (Figure 11, left column) establishes whether there is indeed a *change*, relating broadly to rainfall or temperature. The second level (Figure 11, middle column) identifies *what* has been changing e.g. changes in onset, duration or cessation of rainfall. At each level, the number of respondents not perceiving changes was noted as well and the farmers perceived no change for the general question (no change in temperature or rainfall) were excluded from the next analysis (the pattern). A respondent perceiving there was a change in at least one of the three categories i.e. onset, duration or cessation was considered for the third level of analysis, which focuses on variables such as frequency, intensity, predictability and variability of the perceived changes. In the case of temperature, short rain season, long rain season temperature, or dry season temperature and finally, how it changed was analyzed.

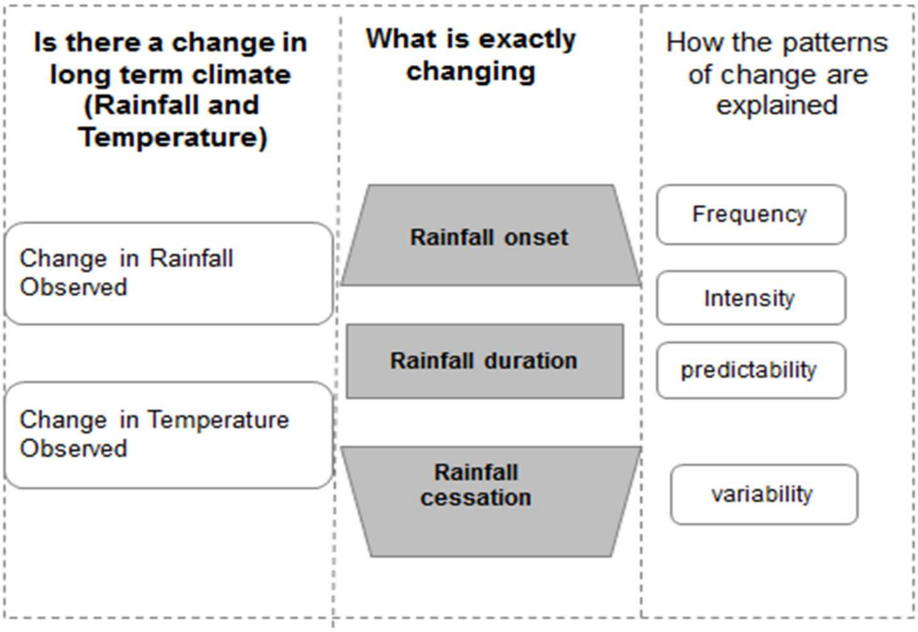


Figure 11: Analytical flowchart matrix to organize quotes on changes in rainfall and temperature.

Source: Adapted from Simelton *et al*., 2013

The temperature and rainfall pattern related variables explained in Table 2 below were compared in 2 dimensions: (1) a temporal dimension, by looking at the situation before (30 years back) and currently (last five years); (2) a spatial dimension, by looking at the food crops and coffee zones.

Table 2: Definition of variables used in the analytical framework

Variables	Description (in comparison with "regular" climate events)
Onset and cessation of rainfall	
Early onset	rainfall onset is perceived (observed) to take place earlier
Delayed onset	rainfall onset is perceived (observed) to take place later
Incomplete onset	Observation of rainfall erratic onset, non-sequential rain start
Early cessation	rainfall is perceived to stop earlier
Late cessation	rainfall is perceived to stop later
Duration of rainfall, frequency, intensity and predictability of rainfall	
Daily durations	Duration of a single rainfall or daily rainfall is reduced
Duration of rainy season	Duration between onset and offset of rainy season is reduced
Frequency of rainfall	Rainfall during a rainy season is observed less frequent
Intensity of rainfall	The daily or seasonal heaviness of rainfall is declined
Predictability of rainfall	Rainfall is less predictable
Inter annual variability	The variability of rainfall from one year to the next is high
Temperature changes	
Extended dry season/month	Observation of extended dry seasons, months or days
Dry season gets warmer	Less uniformity of dry seasons is observed
Less absolute change of seasonal temperature	less absolute change of temperatures with the change in seasons
Extended cooler season/months	Less uniformity of cooler seasons
Daily variability of temperature	Observations of daily variability of temperature
Extended drought	Observation of drought situation

Source: Authors own definition and explanation of variables

Analysis of historical meteorological record

to understand the climate change from the historical meteorological observation, analysis were made and linear trends determined about changes in minimum and maximum temperature, rainfall in the highland and in low altitudes zones, and rainfall patterns (the starting and finishing of rainfall). Statistical significance of the trend analysis was performed using Mann-Kendall test of significance, while the direction and magnitude of the trends was estimated using Sen's slop estimator. A positive slop from the Sen's slop estimator contends an increase in the climatic parameters while a negative slop explains a decrease (Dhanya & Ramachandran 2015; Dhorde & Gadgil 2009; Gadgil & Dhorde 2005). The statistical significance level was set to

$p<0.05$. While computing the rainfall patterns, rainfall outside of the normal growing season were not considered. Onset of the rainy season was defined as the date when more than 20 mm of rainfall had accumulated over three consecutive days and when no dry spell exceeding 20 days occurred within the next 30 days (Akinseye *et al*, 2016). Cessation of rainfall was defined as the end of the rainy season in order to determine the end of the growing season (Oguntunde *et al*. 2014).

3.3. Results

3.3.1. Farmers' perception of changes in climate

Farmers in the study area have been farming in the area for many years ranging between 30 to 80 years and their understanding of climate change was therefore, based on two sources i.e., external information on climate and weather change and own observation from experience and inter-generational knowledge transfer.

A total of 58.3 % of the interviewed farmers have heard about the word or expression of climate and weather change in one or another way. Among the farmers who had heard about climate and weather change, less than half of them had received the information formally from meteorological information dissemination, seminars, NGO consultations and warning systems, while others received it through personal experience sharing and interaction. The FGDs also revealed that coffee farmers appeared better informed on weather and climate changes than the food crops farmers, perhaps as a result of coffee farmers being better off in wealth and social status and hence positing a greater capacity to access information.

Apart from their access and use of official climate information, farmers described changes in climate by describing their personal experiences and observations of how it used to be in the past and how the rainfall and temperature was during the recent years. Farmers repeatedly explained about the changes in seasons, and weather patterns (rainfall and temperature patterns). Farmers' perception was, analyzed in relation to three aspects: (1) change in overall climate, (2) change in rainfall, and (3) change in temperature. A total of nearly 87% of the farmers perceived the overall climate has changed, while 84 and 76 % perceived that either the rainfall has declined or the temperature has increased respectively. Findings from farmers' perception identified three indicators that show climate is indeed changing and affecting their livelihood: (1) the trends observed in the pattern of rainfall, (2) trends in temperature and (3) observations on the effects of the changes such as the natural environment. In addition to these three indicators, farmers also explain the changes in climate in association to their observations of declined crops yield.

Changes in rainfall

Generally, there was consistency in farmers' perception regarding decreasing rainfall although differences were observed on what was actually changing (Table 3). The FGDs revealed that farmers perceived erratic rainfall; shortage of rainfall, and changes in patterns specific to abnormal patterns such as variable onset and offset of rainfall preceded with short duration and less intense of rainfall. The results from individual household interviews also supported the FGDs findings: we found that the onset of rainfall was either delayed, incomplete or both (Table 3). A majority of farmers reported that the onset of rainfall used to be reliable and occurred typically between early to mid-March 30 years ago. Nowadays, however, rainfall onset could occur early April or sometimes mid-April, with no certainty from year to year. Farmers also reported a high probability of incomplete onset with either no sequential rain or rain stopping just after one or two day's rain.

Both coffee and food crops farmers perceived onsets were delayed while most food crops farmers (79%) perceived incomplete onset. Furthermore, most food crops farmers (92%) observed rainfall cessations were occurring earlier than before (Table 3). The food crops farmers' perception of incomplete onsets and early cessations of rainfall may be associated with the hotter temperature causing soil to lose its moisture faster compared to the coffee zone. Beside the onset and offset, duration and frequency of rainfall also affect crop growth. Our study shows that farmers perceived that daily durations of rainfall, and the duration of the growing season (between onset and cessation of rainfall) had reduced significantly. Farmers expressed that rains were frequent and continuous from the starting of the onset to the normal cessation. Lower intensity with sometimes a very heavy rainfall within/out normal rainy season that causes unexpected heavy flooding was becoming characterize climate of the area.

Table 3: Comparative analysis of perceived changes in rainfall patterns by coffee and food crops farmers in Murang'a County

Perception Variability	Coffee farmers		Food crops farmers		t-value
	Mean	SD	Mean	SD	
Onset and cessation of rainfall					
Early onset	0.05	0.360	0.18	0.486	-1.190
Delayed onset	0.95	0.437	0.79	0.462	3.482
Incomplete onset	0.22	0.403	0.78	0.376	-8.898***
Early cessation	0.28	0.453	0.92	0.279	-9.203***
Duration of rainfall					
Daily duration	0.80	0.403	0.90	0.303	-1.536
Duration of rainy season	0.62	0.490	0.90	0.303	-3.809***
Frequency, intensity and predictability of Rainfall					
Frequency of rainfall	0.83	0.376	0.93	0.257	-1.713***
Intensity of rainfall	0.78	0.415	0.93	0.252	-2.392**
Predictability	0.80	0.403	0.93	0.252	-2.173**
Inter annual variability	0.82	0.390	0.93	0.252	-1.917*

Number of observations, n=185 (farmers who did not perceive any change in rainfall were excluded from the analysis).
*,**, and ***Indicates statistical significance at 10%, 5% and 1% level respectively.
Source: Authors survey data, 2014

Note: The column 'mean' in the above Table compares the percentage mean of the farmers perceived there is a change and not perceived a change while the 'SD' is the standard deviation within the group of farmers i.e., coffee and food crops separately. The t-test compares the percentage mean difference in perception across coffee farmers and food crops farmers. In the analysis coffee farmers are assigned value '1' and food crops farmers are assigned value '0'.

Changes in temperature

Farmers perceived several changes with respect to temperature patterns: a prolonged dry season that included dry spells, a change in temperature patterns; extreme sunny dry seasons and extreme but unpredictable cold rainy seasons (Table 4). In their own words, they said that "nowadays, you never know when it will be cold and when it will be hot". The comparison between coffee and food crop farmers revealed that 80% of the coffee and 93% of the food crops farmers who perceived changes further perceived dry seasons, months and days were extended while 34% of the coffee and 78% of the food crops farmers perceived the changes of temperatures according to changes in seasons is less absolute. Other observations such as extended drought (43% of the coffee and 95% of the food crops farmers) reflect that climate change can greatly affect farmers' livelihoods. The significant difference between the coffee and food crops farmers perception may be associated to the actual temperature differences between the two zones which yield different farming systems and livelihood sources.

Farmers reported they are less confident about the onset and offset of the different growing seasons, which translates in to in inaccurate planting and harvesting time. The less absolute onset and offset of the cold season for example made them to be less confident of harvest particularly beans expressed in their own words, they knew exactly when it was time to plant and harvest in the past. This is because beans are harvested during the period of end of long rain season before the dry cold starts. Regarding planting season, farmers prepare their land and wait for the rainfall to come for planting. When it starts to rain, some of them directly start planting, expecting rainfall to fall with regularity while others wait for planting until they become sure of the regularity. Sometimes, the rain fails to be regular and obliges farmers to replant, implying investing again in seeds, fertilizer and labor: this has become a common practice due to the incomplete onset.

Table 4: comparative analysis of coffee and food crops farmers' perception of changes in temperature pattern in Murang'a County

Variable	Coffee zone		Food crops zone		t-value
	Mean	SD	Mean	SD	
Extended dry season/months/days	0.80	0.403	0.93	0.253	-2.173**
The dry season gets warmer	0.65	0.403	0.87	0.481	-3.122**
No absolute change of temperature with seasons	0.34	0.564	0.78	0.512	-5.231***
Extended cooler season/months/days	0.53	0.503	0.20	0.403	4.004***
Daily variability of temperature	0.82	0.278	1.00	0.000	-2.316**
Extended drought	0.43	0.446	0.95	0.220	-3.376***

Number of observations, n=168 (farmers perceived no change in temperature are excluded from the analysis).
*,**, and ***Indicates statistical significance at 10%, 5% and 1% level respectively.
Source: Authors survey data, 2014

Note: 't-value' in the above Table compares the percentage mean difference between coffee and food crops farmers while the 'mean' and 'SD' compares results within a given zone. In the analysis coffee farmers are assigned value '1' and food crops farmers are assigned value '0'.

Perception on the effects of the changes

When farmers were asked to explain the indicators of climate change, the first point they repeatedly explained was the challenges they faced as a result of these changes. Challenges affected the natural environment for agriculture, the land use system and the production of specific crops.

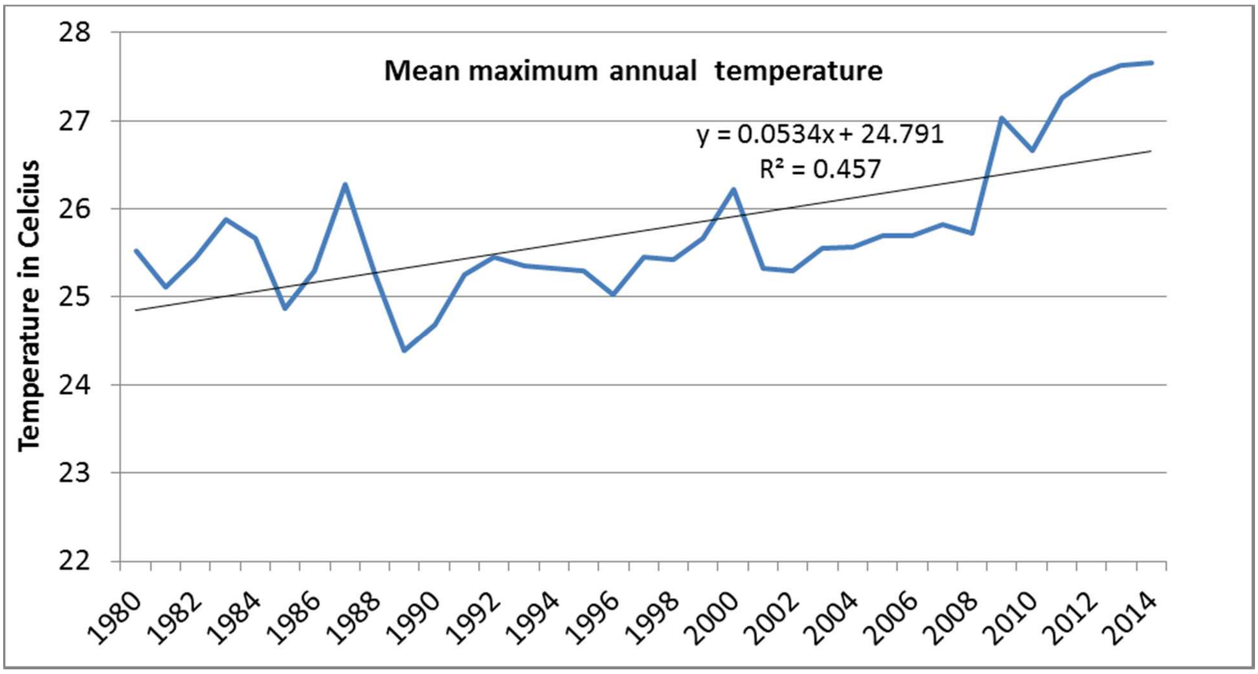
Environmental related indicators include emergence of new diseases for human (malaria), animals and crops such as coffee leaf rust (CLR), coffee berry disease (CBD) and banana weevil. In the lower altitude (what is today part of the food crops zone), coffee used to grow until the 1990s, but nowadays, it has disappeared and has been replaced with short duration maturity crops such as beans and maize. According to farmers' views, the emergence of CBD and coffee stem borer is linked to the changes. As a result, coffee processing factories at the lower altitude were shut down while new coffee societies and processing factories opened at the higher altitude which used to be a high-potential tea zone. Farmers also reported the disappearance of trees such as acacia, the emergence of new drought- resistant weeds, the dwindling of stream flows, and the disappearance of animals like frogs. Farmers also reported decreased yields and production of crops and livestock due to crop and forage failure as a result of erratic rainfall and hot temperatures. Furthermore, planting of improved, high yielding and long maturity crop varieties such as maize, millet and sorghum which could potentially grow well at both altitudes is now restricted to the upper altitude coffee and tea zones, and extreme feed shortages have appeared due to the fact grasses like Napier are not shooting well. Farmers furthermore expressed their interest in adopting drought tolerant crops rather typical of the drier and warmer semi-arid, climates such as pearl millet.

3.3.2. Trend analysis of temperature and rainfall

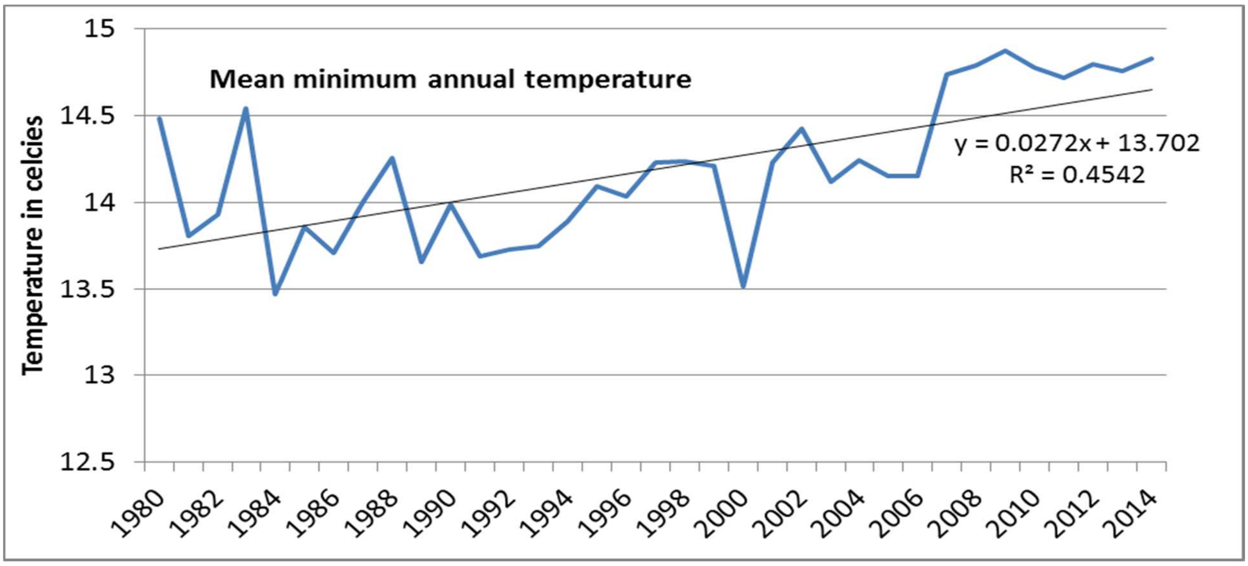
Trend analysis of the long term climate data (1980-2014) clearly shows climate is indeed changing. We detected two types of changes i.e., spatial changes between the coffee and food crops zones on one hand, and temporal changes within each zone on the other had. Mean minimum and maximum temperature (Figure 12a, 12b) shows an increasing trend over time for both the coffee and food crop zones, as confirmed by the Mann-Kendall test and Sen's slop estimators (Table 5). In addition, the mean inter annual variability of temperature (Figure 12c) is also increasing. The increase in temperature for the study area in general was similar with specific results from coffee and food crops zones separate results except the magnitude. We therefore, reported in this paper the results of temperature trend for the county omitting the particular results to conserve a space.

Mean annual rainfall (Figure 13) was higher in the coffee zone compared to food crops zone. For rainfall, the trend analysis indicated a decrease for the coffee zone (Figure 13a), while no clear trend was found by the Mann-Kendall trend analysis and Sen's slop estimator (Table 5, Figure 13b) for the food crops. Besides the trend in annual rainfall, rainfall pattern is also important. To this effect, we analyzed the onset (Figure 14a), and cessation (Figure 14b) of the rainy season on a weekly basis. We considered mid-March as the "standard" onset time against which onset of a given year is compared. The results therefore, indicated a delay in onset and early offset of rainfall is becoming common. Regarding specific periods, our analysis indicates there are at least three different periods. Prior to 1991, onset was early from 1992-2001, onset was very variable and since 2002 onwards; late onset of rainfall characterizes the area (Figure 14a). A similar analysis for rainfall offsets, considering mid-June as the "standard" cessation time shows that rainfall offset time has been steadily declining over time for both the coffee and food crops zones (Figure 14b) since 1980.

(a) Mean maximum annual temperature



(b) Mean minimum annual temperature



(c) Inter annual variability in temperature

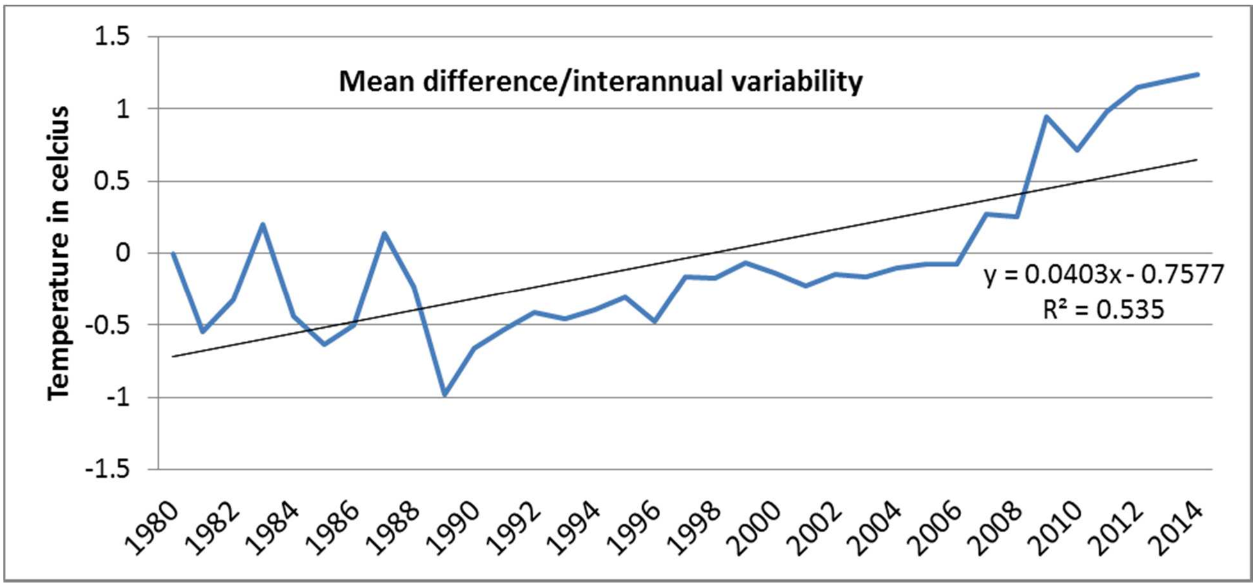
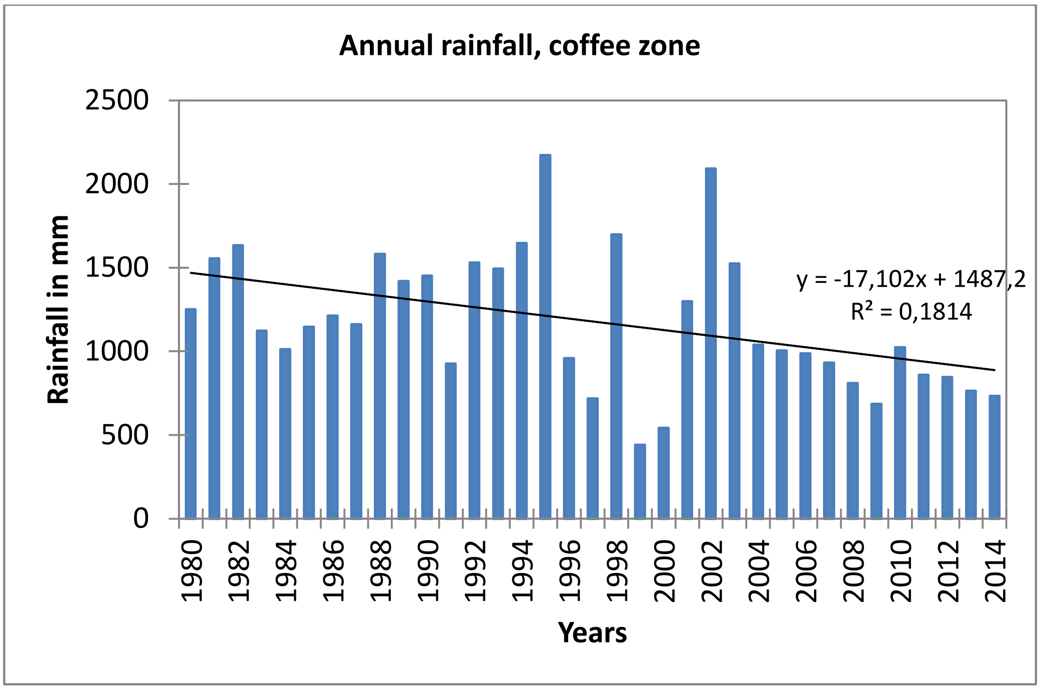


Figure 12: Annual temperature trends of (a) mean maximum, (b) mean minimum and (c) inter annual mean differences in temperatures of the study area (1980-2014)

Data source: Kenya Metreological Department

(a) Annual rainfall of the coffee zone



(b) Annual rainfall of food crops zone

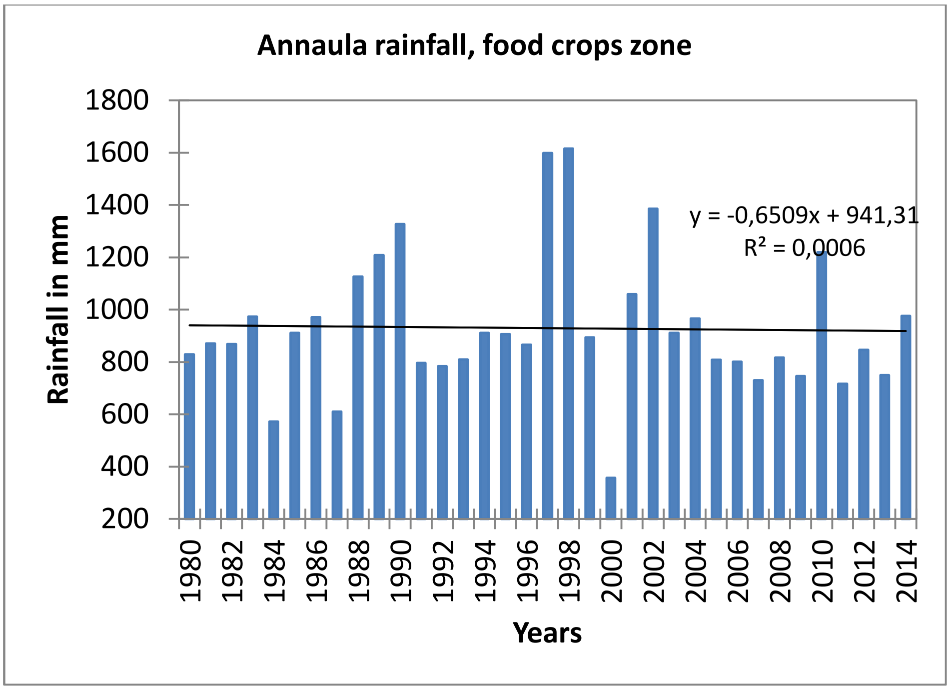


Figure 13: Annual rainfall trends in millimetres of the coffee zone (a) and food crops zone (b), for the years of 1980-2014.

Data source: Kenya Metrological Department

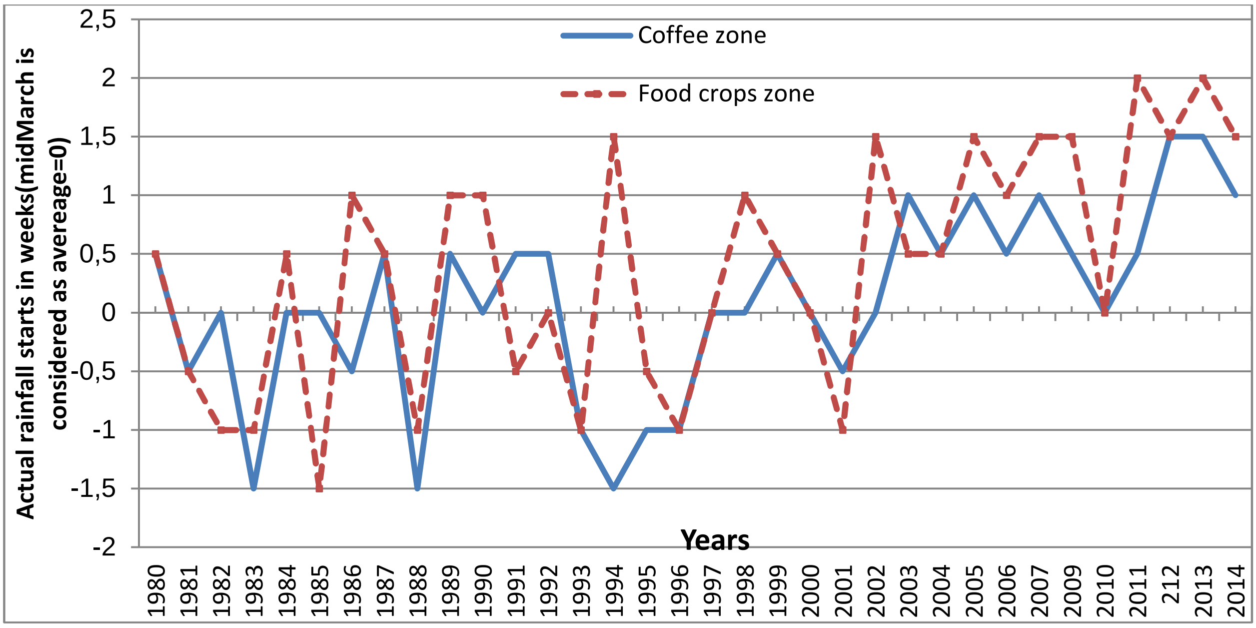
Table 5: Mann-Kendall test of significance

Variable	Mann-Kendall's tau	p-value	Sen's slope	Mean	SD
T Max	0.503	<0.0001**	0.043	25.75	0.80
T min	0.509	<0.0001**	0.032	14.19	0.41
T inter annual variability	0.592	<0.0001**	0.037	0.033	0.56
Rainfall coffee zone	-0.334	0.0040**	-17.100	1179.00	411.50
Rainfall food crops	-0.052	0.6730	-1.485	925.72	262.61
Significance level(%): 5					

**indicates statistical significance at 5% level

Data Source: Kenya Meteorological Department

(a) Onset trends of rainfall for both the coffee and food crops zones in weeks



(b) Cessation trend of rainfall for both coffee and food crops zones in weeks

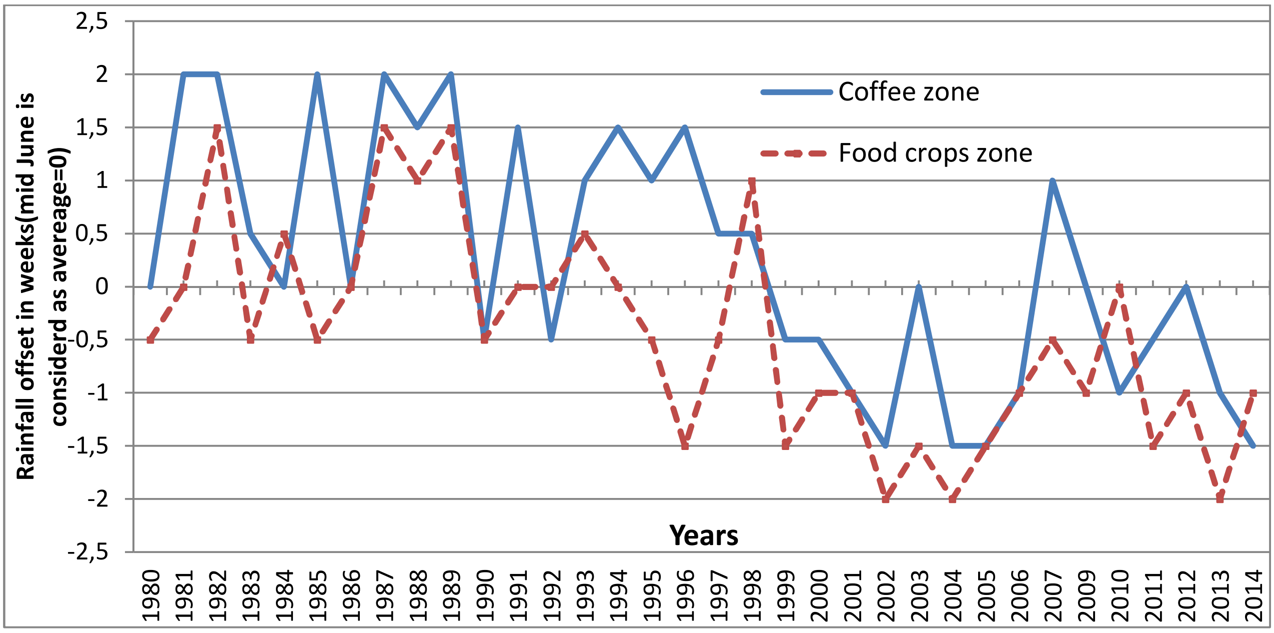


Figure 14: inter-annual variability in (a) onset and (b) cessation trends of rainfall in weeks. Red colour dashed line represents data for the food crop zone while blue line represents data for the coffee zone. Mid-March is considered as standard onset while mid

Data source: Kenya Meteorological Department

3.3.3. Complementarity of farmers' perception and historical data of climate change

The farmers' experience (as evidenced from the FGDs and household interview) confirmed temperature was getting hotter in general. Farmers perceived that dry seasons, days of months or months of a year have extended when comparing the current weather situation to the one occurring in the early 1980s. Farmers further experience that the dry season has gotten drier with no absolute changes of temperature with seasons (Table 6). For instance January used to be hotter month of the year and June and July used to be the coldest months of the year with clear onset and offset of the dry and cold seasons. For its part, the analysis of long term temperature records over the 1980-2014 periods also showed that climate has been changing. Both minimum and maximum temperature has risen with high inter-annual variability (Table 6). This was proved with the Mann-Kendall trend analysis and Sen's slop estimator (Table 5). This depicts farmers' perception of changes in temperature matches with the trend analysis of long term temperature of historical data although farmers' perception does not indicate actual figure.

The overall trend of rainfall from the farmers' perception showed a declining trend to both the coffee and food crops farmers (Table 6). The results from the historical data analysis, however, revealed different results for the coffee and food crops zones: the trend of rainfall in the coffee zone was declining while in the food crops zones, no significant absolute trend was observed (Table 6).

Table 6: summary of farmers' perception and statistical historical data of climate change in Murang'a County

Variables	Farmers' perception	Historical climate data	Observation/ comments
Temperature pattern	Temperature is increasing with extreme sunny and dry seasons of the year, high daily variability, and extended drought	Increase in mean maximum and minimum temperature, high inter-annual variability	Farmers' perception is consistent with the information from the historical data
Annual rainfall	Decreasing annual rainfall (both coffee and food crops zones), erratic	Declining trend in the coffee zone but no absolute significant trend in the food	There is consistency of information between farmers' perception and

	rainfall, shortage of rainfall, either delayed onset or early cessation or both	crops zone.	historical data at the coffee zone while inconsistency is observed at the food crops zone.
Rainfall pattern			
Onset	Abnormal onsets, i.e., early, late or incomplete onsets	Late onset	Consistency between farmers' perception and historical data is observed
Cessation	Inaccurate cessation i.e., early cessation	Early cessation	Farmers' perception is consistent with the information from the historical data
Duration	Daily and seasonal durations are shortened	Short duration	Farmers' perception is consistent with the information from the historical data
Inter-annual variability	Highly variable	Highly variable	Farmers' perception is consistent with the information from the historical data

Source: Authors investigation, 2015

Regarding the rainfall patterns, the coffee farmers perceived majorly a delayed onset while food crop farmers perceived an incomplete and delayed onset of rainfall. This coupled with early cessation, creates squeezing the duration of rainfall which is insufficient for crop maturities. This duration is explained by shorter daily durations and seasonal durations. Farmers of both zones almost equally perceive a high inter annual variability and unpredictability of rainfall beyond the onset and offset disparities. The onset of rainfall analyzed from the measured data reveals rainfall used to start mid-March with some cases of early onset either the end of February or beginning of March. Nowadays, however, rainfall is starting later. The irregularity of rainfall patterns characterized with its onset and cessation is not absolute with little prediction on farming. Unlike annual rainfall measures from the farmers' perception and historical meteorological data analysis, the patterns of rainfall in both zones shows consistency with the historical meteorological rainfall data.

3.4. Discussion and conclusions

This section discusses how the integrated evidence of climate change which coined two sources, i.e., the farmers' perception and historical climate data supports climate change adaptation policy and the need to integrate the two knowledge sources. Using the evidences differently may be a reason for different interpretations to a common problem of climate change. Adaptation as a policy priority may be rhetorically non-controversial but what this means to different actors such as farmers and other scientific communities depend on particular source of information and interpretation.

The long-term rise in temperature evidenced by various studies (Armah *et al*, 2015; Dhanya and Ramachandran, 2015; Kemausour *et al.*, 2011) confirms the consistency of information obtained from both the historical climate data and local farmers' perception in both the coffee and food crops zones. A study by the World Bank (Maddison, 2007) in a broad scope of African countries indicated farmers perceived the climate has become hotter and that long-term climate data from meteorological stations substantiated farmers' perception. Findings from South Africa (Bryan *et al*. 2009) indicated that farmers' perception and recorded data both agreed about the occurrence of a significant increase in temperature. Others such as Silvestri *et al*. (2012); Eriksen & Lind (2009); Adimassu *et al*. (2014) also consistently contended temperature has increased showing mutual results from the historical record and farmers perception. Similar results have been found about the farmers' perception and historical data of rainfall in other coffee growing areas. Mwalusepo *et al,* (2015) found agreements between farmers perceptions and historical data for Mount Kilimanjaro of Tanzania and Taita hills of Kenya.

Discrepancies are however, observed between farmers' perception and historical data of rainfall at the food crops zone: the analysis of annual records of historical data of rainfall provided no evidence to support farmers' perception of declining trends, other than agreeing about interannual variability and pattern differences. For their part, Mwalusepo *et al,* (2015) found inconsistency of farmers' perception and historical data for Machakos farmers in Kenya while consistent results were found for Mount Kilimanjaro of Tanzania and Taita hills of Kenya. Similarly Zampaligr *et al*,

(2014) in western Africa and Simelton *et al*. (2013) in Southern Africa reported a discrepancy between farmers perception and historical data of rainfall. A comparative study of farmers perception and meteorological data of rainfall by Bryan *et al* (2009) showed that there was no clear statistically significant trend of declining rainfall in South Africa over the 1960–2003 periods while farmers for their part perceived a steadily decline.

Why different interpretations are given for a supposedly factual issue and why this matters in the adaptation process could be, therefore, at the center of the climate change reserach. Such differences could occur for three types of reasons:

1) rainfall at the food crops zone was erratic and highly variable throughout the three decades (1980-2014), which in turn could have misled farmers into believing there was a steadily decrease.

2) the average trend for rainfall over the last 10 years (2003-2013) was actually decilding. Were farmers to give more weight to recent recall, it could well explain the apparent inconsistency between farmers' perception and measured data. Lazaru, (2000) showed that farmers perception and experiences are affected by emotion. The decreasing trend for the last 10 years may be the source of emotion leading farmers to perieve the long-term rainfall is decreasing.

3) though there is no clear trends of declining annual rainfall, farmers may actually pay more attention to the trend in rainfall pattern (onset, cessation, duration, frequency, inter annual variability) which affects crop harvest. Solely, this is true that both the perception and historical data showed a variability in the patten of rainfall. This therefore, concludes farmers perception of annual rainfall is affected by the pattern of the rainfall which is a function of production.

Farmers' perceptions also focus on the impacts of the actual changes to their livelihood. The increased in temperature coupled with declining rainfall or rainfall pattern results in declining crop yields. Farmers also reported changed in farming systems such as the disappearance of some crops like sorghum and coffee from the lower altitude. These results are consistent with studies reporting on farmers' perceptions in East Africa such as Mount Kilimanjaro, Taita hills and Machakos (Mwalusepo *et al*, 2015) and Uganda (Hartter et, 2012). Delay in onset of rainfall in Southern India was found to affect the date of planting of crops and lead to poor performance of crops, obliging farmers to develop specific adaptations such as delay planting and irrigation adoption (Dhanya & Ramachandran 2015).

The main question here is, what is the impact of such complementarity or discrepencies of the two knowledge sources (farmers' vs. meteorological data) when it comes to adaptation to climate change. Though the farmers perceptions correlate with the historical data analysis which mostly used by scientists for policy decisions, there is discrepancies in adaptation needs to climate change. On one hand, farmers for their part seem keen on bringing changes to their agronomic practices. This includes changing cropping sytems, crops and varieties (Dhanya & Ramachandran 2015; teucher *et al*., 2016), changing crop calendar and farm operations (Dhanya & Ramachandran 2015: Abid *et al*. 2015: Deressa *et al*. 2011), changing the mix of enterprises they implement between crop-and livestock (Seo 2010: Thornton & Herrero 2014), shifting cropping systems for example shifting from coffee to drought resistance food crops such as millet (Teucher *et al.* 2016) or shifting to more diversified income sources (Dhanya & Ramachandran 2015: Tefera *et al*. 2004).

Policy actors on the other hand, prefer macro-level long term investment strategies such as institutional building for vertical and horizontal collaboration among different institutions (Bizikova *et al*. 2014), capacity enhancement of the financial sector that provides credit and insurance for farmers (Dhanya & Ramachandran 2015), improving climate information services through installation and management of meteorological stations and ensuring the flow of information (Vincent *et al*. 2015), multi-level institutional linkage, networking and formation of policy platforms of different stakeholders (Rodima-Taylor *et al*. 2012: Dhanya & Ramachandran 2015).

Location specific adaptation and actual practice by farmers to adapt to the changing climate would be equally important as the information available and needed for climate change policy. This helps to understand if the adaptation needs and actions are based on the information available from different sources. This also helps to understand if adaptation needs and actions are based on the same kind of information. The orthodoxy may also depend on the interpretation of the information which leads different actors to have different views. O'Brien *et al*. (2007) points out that in the scientific framing, adaptations are made in response to different scenario of future greenhouse gas emissions derived from projected future climate change. Farmers' response on the other hand depends on past experiences and actual impacts and strategies are made in connection to observed weaknesses in practice (Armah *et al*., 2015; Dhanya & Ramachandran 2015).

Adaptation policy have to take in to account, therefore" (1) the spatial disparities as farmers in different locations and systems differ in adaptive capacity and knowledge of climate change, and (2) temporal difference as the rate of climate change depends on emission rates of different times preferably the future climate is uncertain which demands flexible adaptation policies and strategies. Moreover, farm level determinants of adaptation to climate change have to be taken in to account in the development of adaptation policies. The coordinated knowledge of farmers, researchers, private sector and local government could be a potential input for better service of adaptation. Farm level adaptation requires farmers to perceive the changes and act upon perceptions while institutions need to support them with necessary resources, technologies, and training.

CHAPTER FOUR
CURRENT CHOICES AND FUTURE NEEDS: FARMERS RESPONDING TO PRESSURES AND THEIR PERCEPTION OF CLIMATE CHANGE IN CENTRAL KENYA

4. CURRENT CHOICES AND FUTURE NEEDS: FARMERS RESPONDING TO PRESSURES AND THEIR PERCEPTION OF CLIMATE CHANGE IN CENTRAL KENYA

Kinfe Asayehegn[1], Ludovic Temple, Berta Sanchez, Ana Iglesias

Abstract

Farmers are experiencing the need to adapt to climate change, and are developing different strategies. This article aims to contribute to an understanding of farmers' adaptation choices, determinants of the adaptation choices, and the implication of the adaptation choices in relation to household income. Focus Group Discussions (FGDs) and 220 household surveys were applied to farmers in the coffee and food crop zones in Central Kenya during 2014. The Heckman model was used to evaluate the determinants of adaptation choices and their marginal effect. Farmers from the coffee and food crop zones perceive and adapt to climate change differently. Farmers who are aware of changes in climate are found more willing to explore adaptation strategies. A positive relationship is found between adaptation to climate change and household income. The highest payoff/return is achieved if multiple adaptation choices are used rather than a single strategy. The choices of strategies are also determined by household characteristics, resource endowment, institutional variables, and climate information. The strong correlation between the socio-institutional variables and adaptation capacity suggests the need for the establishment and strengthening of local institutions, such as micro-finance and extension.

Keywords: Climate change adaptation; coffee; farmers; Kenya

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Résumé

Les agriculteurs doivent s’adapter au changement climatique, et développent pour cela différentes stratégies. Cet article contribue à la compréhension des choix d’adaptation des agriculteurs, de leurs déterminants et implications, en lien avec le revenu des ménages. Des groupes de discussion et des enquêtes ont été réalisés en 2014 auprès de 220 producteurs de cultures vivrières et de café dans le centre du Kenya. Le modèle d’Heckman a été utilisé pour évaluer les déterminants des choix d'adaptation et leurs effets marginaux. Les producteurs vivriers et de café perçoivent et s’adaptent différemment au changement climatique. Les agriculteurs qui sont conscient du changement climatique sont plus disposés à explorer différentes stratégies d’adaptation. Une corrélation positive est identifiée entre l’adaptation au changement climatique et l’augmentation du revenu des ménages. Des choix d’adaptation multiples sont plus payants que le choix d’une seule stratégie. Les stratégies d’adaptation sont aussi déterminées par les caractéristiques des ménages, les dotations en ressources, les variables institutionnelles et l’information relative au climat. La forte corrélation entre les variables socio-institutionnelles et les capacités d’adaptation suggère le besoin de renforcer les institutions locales de microfinance et de conseil technique.

Mots-clés: Adaptations aux changements climatiques ; café ; agriculteur ; Kenya

Resumen

Los agricultores están experimentando la necesidad de adaptarse al cambio climático, y están desarrollando diferentes estrategias. Este artículo tiene como objetivo contribuir a la comprensión de las opciones de adaptación de los agricultores, los determinantes de las opciones de adaptación y la implicación de las opciones de adaptación en relación con el ingreso familiar. La zona de estudio es la región central de Kenia. En 2014, se aplicaron discusiones de grupo de enfoque (FGD) y 220 encuestas de hogares a los agricultores en las zonas de café y de cultivos alimentarios en Kenia Central. El modelo de Heckman se utilizó para evaluar los determinantes de las opciones de adaptación y su efecto marginal. Los

agricultores de las zonas productoras de café y alimentos perciben y se adaptan al cambio climático de manera diferente. Los agricultores que son conscientes de los cambios en el clima se encuentran más dispuestos a explorar las estrategias de adaptación. Los resultados muestran una relación positiva entre la adaptación al cambio climático y el ingreso familiar. El rendimiento / rentabilidad más alto se logra si se utilizan múltiples opciones de adaptación en lugar de una sola estrategia. Las opciones de estrategias también están determinadas por las características del hogar, la dotación de recursos, las variables institucionales y la información climática. La fuerte correlación entre las variables socio-institucionales y la capacidad de adaptación sugiere la necesidad de establecer y fortalecer instituciones locales, como el micro financiación y la extensión.

Palabras clave: Adaptación al cambio climático; café; agricultores; Kenia

4.1. Introduction

One of the most widespread anthropogenic challenges affecting agricultural production is climate change and climate variability (Torquebiau, 2016; Molua, 2008). An adjustment to the actual or expected changes has to be, therefore, among priorities in policy decisions. Farmers' behavioural change towards adaptation and willingness to take action are as important as are policy decisions (Banna et al., 2016; Garcia de Jalon et al., 2013).

The need for adaptation to ensure food security, particularly in Africa, is highly justified and supported at the political and policy levels (Yegbemey et al., 2014; Sowers et al., 2011). These policy level adaptation needs are insufficiently supported by local level farmers' choices and options (Souza et al., 2015). The difficulty in understanding farmers' choices of adaptation holds back the development of concrete measures. This shows, the success of various policy proposals has been limited, reflecting a difficulty in linking policy studies to real local farmers' contexts, needs and capacities (Garcia de Jalon et al., 2013).

Studies concerning farmers' adaptation choices and determinants of choices are insufficient, unlike analysis of public perception (Merot et al., 2014; García de Jalón et al., 2013). Two points are noted in this regard: - (1) there is a considerable micro studies on attitudes of the African farmers to climate change (Fosu-Mensah et al., 2012; Silvestri et al., 2012; Okonya et al., 2013; Mertz et al., 2009; Patt and Schroter, 2008; Maddison, 2007). (2) Large surveys have also addressed farmers' perceptions towards climate (Nhemachena & Hassan, 2008; Maddison, 2007), and ethnography has outlined how limiting factors relate to adaptation choices at a conceptual level (Souza et al., 2015 ; Angeon and Caron, 2009), where representation of local context is one of the limitations.

This study, therefore, bridges the massive surveys and the ethnographic approaches, examining the relations between perception and adaptation, in order to explore the reasons behind the farmers' choices. Even at a local context, perception and adaptation to climate change varies across production systems due to the difference in opportunities and determinants. In the rainfed crops production, adaptation for instance comprises practices, such as adopting drought resistant varieties (Teucher et al. 2016), or intercropping of different crops (Lobell *et al*., 2008), while changing breeds, and alternative feeding strategies (Seo, 2010) are common in the livestock sector. This paper addresses three questions: (1) are adaptation choices similar among farmers of the coffee and food crop zones of the study area? (2) What determines the adoption of adaptation choices to climate change of the coffee and food crop zones? (3) What are the implications of the adoption of different adaptation choices to household income of the study area? This research is framed in a context, where (1) economic and climate pressures are already major issues and all climate scenarios project further temperature increase (see Asayehegn et al., 2016), (2) policy actors are starting to look for micro studies on farmers' action (World Bank, 2016), and (3) affected farmers contribute to almost 65% of the local economy, and 50% of principal export earnings (Republic of Kenya, 2015).

This work attempts to advance the existing knowledge of climate change adaptation by presenting real cases (i.e. farmers from the coffee and food crop zones in Kenya), where respondents are directly affected by the recent changes in the economy and the climate and, where these changes have affected negatively their wellbeing. The Heckman model was used both to evaluate the main factors influencing farmers to choose climate change adaptation strategies and its marginal effect. The results of this research are valuable contributions to climate change policy in Africa, since knowing how coffee and food crops farmers at a local context responds to changes could help to better targeting for adaptation projects and programs.

4.2. The Murang'a case study in Central Kenya

The study was conducted in Murang'a County, Central Kenya, an area with diversified physical environments and climatic extremes (World Bank, 2016). Historically, coffee in the area was one of the important crops for farmers' income and for the Country's foreign exchange earnings. National coffee production was on an increasing trend for a long time; it increased from 43,778 tonnes in 1963/64 to 140,000 tonnes in 1987/88 (Thuku, 2013). After 1988, however, coffee production has been in constant decline. Production has declined and stagnated at about 50,000 tonnes, and its world market share has declined from 3.2% in 1987 to 0.6% in 2006 (Thuku, 2013).

Environmental dynamics and climate change were the main factors for the steady decline of production (Davis *et al.,* 2012). Coffee, especially Arabica, grows at an average temperature between 18 ^{0}C and 21 ^{0}C (Lin, 2007) and at an annual rainfall of 1500-3000 mm (Wrigley, 1988). However, rainfall reduces from time to time while hot periods become more common. As a result, coffee plants tend to dry, while pests and diseases develop, affecting many coffee growers (Jaramillo *et al*., 2013). Because of these constraints, two zones, which are changing over time existed in the area, i.e., coffee and food crop. The two zones (Figure 15) differ in altitude (the food crop ranged below 1450 masl, while the coffee zone covers the altitudes between 1450 through 1800 masl), types of production systems (coffee is the dominant crop in terms cultivated land area, and share of income in the coffee zone, while food crops are dominant in the food crop zone), and climate (the coffee zone is comparatively cooler and has higher annual rainfall).

The food crop zone on the other hand, is characterized by semiarid climatic conditions with a high potential for droughts. Rainfall is erratic, uncertain and unevenly distributed in two distinct growing seasons. Both seasons are, however, characterized as a short to very short growing period. Simulations predict that yields of main crops is in decreasing trend. Future climate projections show the agroecological situation will be further aggravated and substantiate the introduction of drought-resistant crop varieties (Lobell *et al.,* 2008).

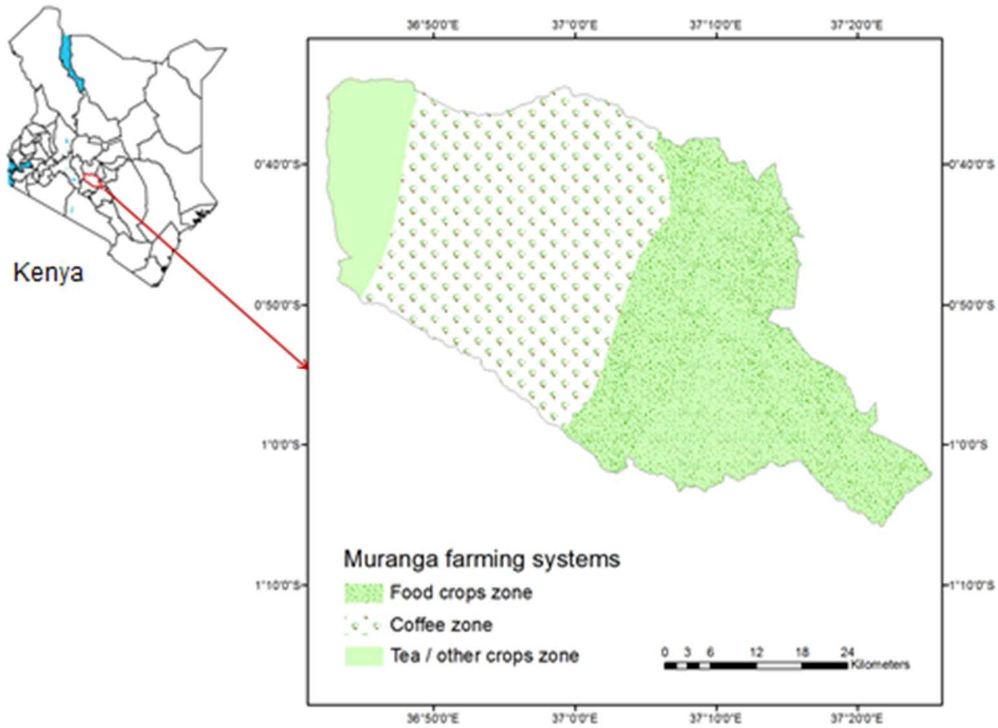


Figure 15: Geographical location of the Murang´a County, Kenya

4.3. Methods

4.3.1. Framework and rationale for model development

We first identified and characterised the major adaptation choices by analysing changes by household members, including investments in livestock management, crop-livestock mix, tree planting, new crop varieties, changes in planting dates, irrigation, and soil and water conservation. We compared the implementation of adaptation strategies within and across the two zones. Based on their importance to the farming community as best options to adapt to climate change and a high rate of adoption, we chose three adaptations: crop-livestock diversification (MIX), changing crop varieties (VAR), and irrigation supplementation (IRR), and their combinations, for further analysis (Figure 16 and Table 7). The adoption of different crop varieties also confirms difference in agronomic performance of crops varieties and leads to different levels of resistance to changing climate. In the eastern province of Kenya, Teucher *et al*., (2016) finds that several high yielding crops varieties, such as maize, are facing a significant yield decline, while drought resistant crop varieties, such as pearl millet, are currently suitable for the area. The proposed framework for analysing choices is, therefore, outlined in Figure 16.

Table 7: Percentage distribution of sample farmers across the selected choices

Choices (j)	Adaptation strategies	Crop-livestock diversification	Variety change	Irrigation adoption	percentage adopted
1	No change (NO)				27.7
2	Crop-livestock diversification(MIX)	x			10.8
3	Varity change (VAR)		x		8.3
4	Irrigation adoption (IRR)			x	10.0
5	Diversification + variety (MIXVAR)	x	x		15.8
6	Diversification + irrigation (MIXIRR)	x		x	9.2
7	Variety + irrigation(VARIRR)		x	x	8.4
8	Diversification + variety + irrigation (MIXVARIRR)	x	x	x	10.0
Total					100

Note: The binary triplet represents the possible strategy combinations. Total number of observations (n=220)

The choices (options for households' to adapt the changes) are categorized into eight categories (see Table1) i.e., no adoption of choices at all (NO), crop-livestock diversification (MIX), variety change (VAR), adoption of supplemental irrigation (IRR), crop-livestock diversification and variety change (MIXVAR), crop-livestock diversification and supplemental irrigation(MIXIRR), variety change and supplemental irrigation(VARIRR), and combination of all the three crop-livestock diversification variety change and supplemental irrigation(MIXVARIRR). The choice of strategies depends on the effects of current climate trends and climatic variability, the effects of current economic pressures on the farm, and the farmers' perception of climate change. The choices that farmers currently make are derived from the consultation process (focus groups and a survey). These choices are affected by a large set of explanatory variables (19) related to individuals' socio-demographic and environmental characteristics, that are categorized in to seven groups (household characteristics, resource endowment, institutional setting, climate change perception, information on climate and forecasting, farm management and agroecological zone).

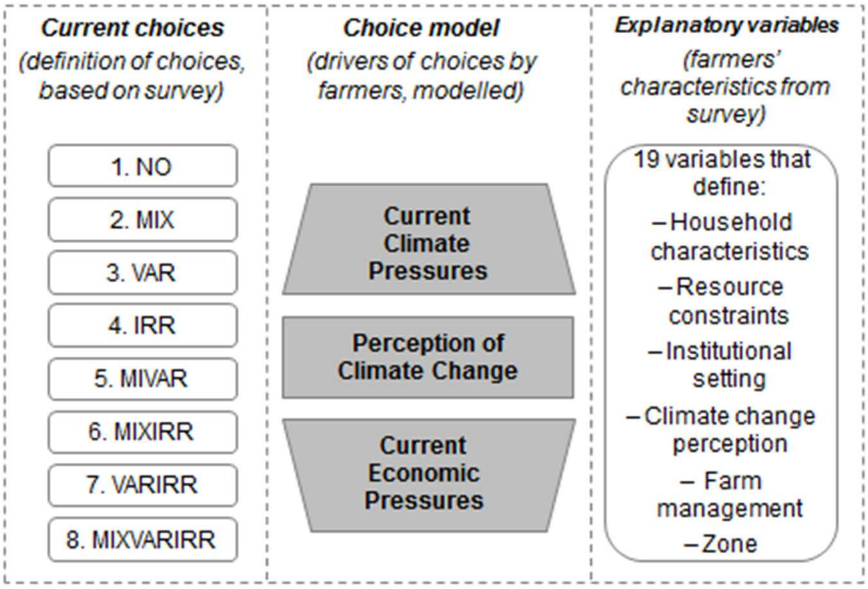


Figure 16: Proposed framework for analyzing farmers' adoption of innovation strategies

4.3.2. Data collection

4.3.2.1. Sample

Primary data on the adaptation choices was collected by means of two social research methods used in sequence: Focus Group Discussions (FGDs) and household survey. The household survey was conducted via face to face during June-October, 2014. The sample consists of 220 farm households equally stratified to coffee farmers (110) and food crop farmers (110).Regarding the distribution of samples by adaptation choices (Table 7), 27.72% of the samples are none adopters of any choice while the rest 72.27% adopted different choices and distributed in to seven categories as presented in Table 7. Prior to the household survey, eight FGDs were conducted with about twelve farmers per group. Discussions with two groups per each of the following areas were conducted; coffee-tea intersection of the upper highland, potential coffee area where better quality coffee is produced, marginal coffee area where coffee is leaving its place to food crops and the complete food crop of the lower altitude respectively. The aim was to understand the community wide problems and choices on view of climate change and to ensure the surveys were well worded and relevant.

All respondents were farmers where some combine crop production with livestock activity (48.18%). The majority of the farmers were male headed (64%) which is equivalent to the ratio of male and female household heads of the total rural population of the county computed from the national population survey in 2009. The majority of the household heads were between 30 and 60 years of age (58.4%) and the rest (41.6%) were elders over 65 years age. Only a small fraction of the farmers completed primary education (34.5%). In relation to land ownership, 86% of farmers were owners of their own farm land. Only 6.7%had more than 5 acres with maximum of 9.8 acres, 52.2% owned land size between 2 to 5 acres, and 40.8 % had less than 2 acres.

4.3.2.2. Questionnaire

The survey was composed of 36 questions in total including check-all and forced-choice questions followed by a comprehensive discussion with the farmers. Prior to the survey, we formulated the questions according to the following list;- (1) access to information on climate and forecasting; (2) farmers perception, and concern for climate change, (3) the current adoption of the selected adaptation innovations, (4) characteristics of the household (including gender, age and education of the household head, and family size of the household), (5) household resource endowment (i.e. total farm size, farm income, offarm income, livestock ownership and distance to market of the household), (6) institutional setting (i.e. access to credit, extension and cooperatives of the household), (7) access and use of farm inputs (i.e. innovative practices, manure, compost, mulching, improved seed, fertilizer) and (8) agroecological zone(i.e. coffee and food crops zone).

First, the percentages of the farmers have access to climate related information from both the scientific knowledge and indigenous knowledge was calculated. A value of ‘1’ was assigned to the farmers who have access and ‘0’, otherwise. Second, three questions were used to measure the scale of farmers’ perception and concern of climate change (i.e. one that evaluates the understanding of climate in general and the other two are specific to rainfall and temperature). Farmers responded ‘yes’ to the general question or ‘increased/decreased temperature’ and rainfall’ were considered as perceived changes. Third, the scale to measure the current adoption of the selected adaptation innovations consists of 13 questions with ‘yes’ or ‘no’ response. A value of ‘1’ was assigned if the farmer has adopted new/improved strategies according to the list in the questionnaire and ‘0’ otherwise. Fourth, out of the household characteristics questions, gender of the household head was formulated as a binary option with value ‘1’ if the household is male and ‘0’ otherwise. Age and education of the household head and family size of the household were formulated as open questions. Fifth, household resource endowment i.e. total farm size, farm and offarm income, livestock owned and distance to market was formulated as open questions. Farm income was consisting of all the incomes from farming for the year 2013/14. Sixth, for the households’ access to institutions (i.e. access to credit and extension), the values ‘1’ was used if the household had access and ‘0’ otherwise. Seventh, farmers’ innovative practice, access and use of farm inputs was formulated as ‘yes’ or ‘no’ response and finally, agroecological zone was considered as ‘1’ if the zone is coffee zone and ‘0’ for food crops zone.

4.3.3. Choice model

Decision making depends on choices. As explained by Hunt *et al*., (2005), choice models assume utility maximization. In the area of climate change adaptation innovations which satisfies this assumption, farmers may be unable to adopt their most preferred innovation due to uncertainty in the realization of choices as a result of different drivers including inadequate climate information (Deressa *et al*., 2009), partial understanding of climate impacts and uncertainty about benefits of adaptation (Iglesias *et al.*, 2011), perception and concern towards future change (Maddison, 2007), disconnect between climate science and policy leading to a lack of use-inspired research (Molua ,2008), insufficient institutional infrastructure such as access to credit and extension services (Bryan *et al*, 2009), and weak market systems (Bardaji & Iraizoz, 2014).

Empirical studies such as Abid *et al.*, (2015) and Bryan *et al*., (2013) used a binary logit regression to measure adoption choices by classifying the dependent variable in to binary option as adopted choices and not adopted. Farmers, however, differ in choices of adopting the strategies (some adopts single choice while others adopt multiple of choices). Applying binary logistic regression is, therefore, inappropriate to evaluate if adoption of combination of adaptation choices is better over the adoption of single choices. This was also explained in Deressa *et al.*, (2008) as an advantage, MNL model allows the analysis of adoption options across more than two alternatives.

The choice of adoption of innovations in this study is, therefore, modelled as a choice between two alternatives: 'adopted choices (at least one of the options of MIX, VAR, IRR, MIXVAR, MIXIRR, VARIRR or MIXVAIRR) and 'no strategy' represented as 'NO' (see Figure 16 and Table 7). We, assume farmers aim to maximize their utility or profit, y_i, by comparing the utility/benefit provided by j alternatives. Let y denote a random variable taking on the values (1, 2.. J) for J a positive integer, and let x denote a set of conditioning variables. y denotes choices and x contains the drivers such as household, institutional and other variables (Table 8). Therefore, the expected benefit, y_{ij}^*, that the farmer derives from the adoption of choice j is a latent variable (wooldridge 2011):-

$$y_{ij}^* = x_{i\beta_{j+\varepsilon_{ij}}} \tag{1}$$

Table 8: Explanation of the terms used in the choice model equation

Symbols in the equation	Measure	Description
y	Expected benefit	Perception of expected benefit from adopting a given choice by the farmer
i	A farmer with the lists of choices to decide either to adopt or not	A farmer, who is a decision unit either to have at least one of the choice or not
j	Lists of adaptation choices	Lists of adaptation choices (NO, MIX, VAR, IRR, MIXVAR, MIXIRR, VARIRR, MIXVARIRR).
x	Explanatory variables	Independent variables affecting the choices of adoption of innovation choices (the 19 variables explained in Table 7)

y_i	Utility/benefit of the i^{th} farmer	The perceived utility/benefit of the i^{th} farmer from choosing adoption choices
y_j	Utility/benefit of a farmer from choice j	The perceived utility/benefit of a farmer from choosing alternative j which contains the lists of options.
ε	Random component	Error term
x_i	Deterministic components,	the independent variables determining the adoption choices

The assumption that can be derived from the above equation is that the co-variate vector meaning the explanatory variables of the regression $\mathbf{x_i}$ is un co-related with the error term or deterministic component (ε_{ij}) specified as:-

$$E\left(\frac{\varepsilon_{ij}}{x_i}\right) = 0$$

The parameter estimates of the MNL model explains how citrus paribus changes in the elements of x affect the response probabilities P(y=j/x), j= 1, 2 …J as the probabilities have to sum, P(y=j/x), is determined after analysis of the probabilities for j=2, . . .J. let x be a 1× K vector with first element, then the MNL model has the probabilities of as explained bellow;

$$P_{ij}(y = {}^{j}/_{x_i}) = \frac{\exp(x_i\beta_j)}{(1+\sum_{h=1}^{J}\exp(x_i\beta_h), \quad j=1\ldots\ldots J)} \qquad (2)$$

β_j isK×1, j=1,2. . .,J

The distribution assumes ε_{ij} are independent and identically distributed, that leads to an assumption, the Independence of Irrelevant Alternatives (IIA). For the MNL, we assume probability of using a certain choice by a given farmer needs to be independent from the probability of choosing another P_j/P_k is independent of remaining probabilities (Deressa *et al*., 2009). We, therefore, define the second stage of the Heckman model i.e., the OLS:-

$$\frac{\partial\rho_j}{\partial x_k} = P_j\left(\beta_{jk} - \sum_{j=1}^{J-1} P_j\beta_{jk}\right) \qquad (3)$$

The marginal effects or probabilities which support the parameter estimates measure the expected change in probability of a particular choice being made by a farmer with respect to a unit change in an explanatory variable from the mean and is a function of the probability itself (Deressa *et al*., 2009).

4.3.4. Description of explanatory variables

Based on review of literature from similar empirical studies such as (García de Jalón *et al.,* 2015), 35 explanatory variables were selected. But specific to the study area with in our scope 24 explanatory variables (Table 9) such as : i)Household characteristics (i.e., gender, family size, age, education); ii) Resource constraint (i.e., farm size, total farm and of farm income, total livestock, experience of the household head, distance to input and output market);iii) Institutional (i.e., access to credit, access to extension, cooperative membership); iv) Climate change (i.e., perception on climate change, access to information on climate, weather changes and forecasts, traditional knowledge on weather forecasting); v) farmers' innovative practice in access and use of farm inputs (innovation performance, access to resources such as manure, compost, fertilizer, improved seed and mulching); vi) Zone (coffee or food crop farmers) were found important. Households' access to improved seed and fertilizer were excluded from presenting in the results as no difference was found between farmers in access and use.

Previous studies claims that higher level of education, increasing in farm size, farm income and household size increases the probability of choice of adoption of adaptation strategies such as tree planting, crop-livestock diversification and variety change (Abid *et al*., 2015). Gebrehiwot *et al*, (2013) finds a positive relationship between variables such as frequency of extension service, availability of farm credit and climate information with crop diversification. Input use such as manure and compost negatively correlate with household adaptation choices such as cropping system diversification and improved variety change (Teklewold *et al*., 2013). According to Maddison (2007) there are two important components to adaptation: perception and adoption of strategies. Implementation of choices requires that the farmers perceive a change in the climatic conditions. Constraints in farm credit, extension services, lack of access to land and information about climate change are negatively correlated to adaptation (Bryan *et al*., 2009) where policymakers are recommended to pay attention on small-scale subsistence farmer and enhance adaptation providing access to information, credit and markets.

Table 9: Description of explanatory variables

Explanatory variables	Description and unit of measurement	Mean	Std. Dev.
Household characteristics			
GENDER	Dummy takes the value 1 if the head is male and 0 otherwise	0.64	0.48
FAM	Continuous, family size of the household in adult equivalent	3.58	1.48
HHHEDU	Continuous, education of the household head in number of years	6.47	3.63
Resource constraint			
FARMSIZE	Continuous, farm size holding of the household in acres	2.60	1.84
INCOMFARM	Continuous, farm income of the household head in ‘000’USD	1.91	3.18
OFFARMINC	Continuous, offarm income of the household in ‘000’USD	0.91	1.63
TLU	Continuous, total livestock ownership in TLU	1.59	1.03
DISTANCE	Continuous, distance to market in KMs	4.86	3.08
Institutional settings			
CREDIT	Dummy, takes the value 1 if have access to credit and 0 otherwise	0.62	0.49
EXTENSION	Dummy, takes the value of 1 if access to extension and 0 otherwise	0.38	0.48
Information and perception			
INFORMAT	Dummy, takes value 1 if have access to information and 0 otherwise	0.48	0.49
TRADKNOW	Dummy, takes value 1 if head have IK of forecasting and 0 otherwise	0.52	0.50
PERCEPTION	Dummy, takes value 1 if head perceive climate change and 0 otherwise	0.87	0.34
Access and use of farm inputs			
INNOVATIVE	Dummy, takes the value 1 if household	0.46	0.52

	head experienced in experimentation new farm inputs and 0 otherwise		
MANURE	Dummy, takes value 1 if prepares and uses manure and 0 otherwise	0.45	0.50
MULCHING	Dummy, takes the value 1 if practice mulching and 0 otherwise	0.25	0.43
COMPOST	Dummy, takes value 1if prepares and uses compost and 0 otherwise	0.20	0.40
Agro-ecological zone			
COFFEE	Dummy, takes the value 1 if the zone is coffee and 0 otherwise	0.50	0.50
FOODCROP	Dummy, takes the value 1 if the zone is food crop and 0 otherwise	0.50	0.50

4.4. Results

4.4.1. Defining farming systems

Results (Table 10) show that 72% of farmers from the coffee zone and 57% of food crop zone are male-headed households. This may relate to the significant number of farmers from the food crop zone who use off-farm employment and temporary migration for casual work. Household heads at the coffee zone were higher in their education level by a factor of three years compared to farmers from the food crop zone. Farmers from the coffee zone had higher farm and off-farm incomes when compared to the farmers from the food crop zone. Farmers from the coffee zone had better institutional services such as credit and extension. This may depend on the access, farmers' information and attitude towards the services. The results showed that the number of farmers from the coffee zone who had access and use of information exceeds that of farmers from the food crop zone by 30%. Farmers from the food crop zone were, however, found to have better access and use of traditional knowledge on climate forecasting and information sharing.

In total, 86.82% of the farmers perceived the overall climate to have changed, while 84.09% and 76.36% respectively perceived that the rainfall has declined and that temperature has increased during the last 30 years. The discrete analysis of coffee and food crop revealed that farmers from the food crop zone have better understanding that the climate has changed. This might be in relation to perceived impacts of the changes. Farmers from the food crop zone explained that crops failure due to erratic rainfall and heat stress was frequent. Farmers from the coffee zone were more innovative in input use and management. The number of farmers used manure and compost to improve their production and productivity was higher in the coffee zone than the food crop zone (Table 10).

Table 10: Defining coffee and food crops farmers of the study area

Household Characteristics	**Coffee farmers**		**Food crop farmers**		**t- value**
	Mean	**SD**	**Mean**	**SD**	
GENDER	0.72	0.45	0.57	0.50	1.720*
FAM	3.52	1.76	3.67	1.60	-.488
HHHEDU	9.05	3.74	4.01	3.14	3.883***
Household access to assets and resources					
FARMSIZE	2.679	1.862	2.525	1.561	0.480
INCOMEFARM	2.737	4.153	1.088	1.304	2.933***
OFFARMINC	1.199	1.954	0.621	1.160	1.970*
TLU	1.735	1.030	1.442	1.013	1.573
DISTANCE	4.290	2.900	5.430	3.130	-2.924***
Institutional variables					
CREDIT	0.77	0.42	0.47	0.50	3.523***
EXTENSION	0.48	0.50	0.28	0.45	2.283**
Access to climate related Information					
INFORMAT	0.63	0.48	0.33	0.50	3.107***
TRADKNOW	0.39	0.37	0.63	0.50	-4.523***
PERCEPTION	0.83	0.36	0.91	0.18	-2.242**
Access to farm inputs					
INNOVATIVE	0.57	0.50	0.35	0.63	0.182**
MANURE	0.57	0.50	0.33	0.47	2.620***
MULCHING	0.30	0.46	0.20	0.40	1.793
COMPOST	0.28	0.45	0.12	0.32	3.286**

Note: The column "mean" in Table 10 compares the farmers within the group while the "t-statistics" compares the inequality across groups.
Number of observations (n=220).
*, **, and *** Indicates statistical significance at 10%, 5% and 1% level respectively.
Source: Survey data, 2014

4.4.2. Defining farmers' choices

Crop management choices

Farmers from both the coffee and the food crop zone had access to different crop varieties (i.e., local or commercial). The local varieties were known for their early maturity and drought resistance, while the improved commercial varieties were preferred for their productivity. Rainfall at the coffee zone was variable, while the rainfall at the food crop zone was usually less than three months. Thus, farmers of the food crop zone were forced to use short maturity varieties, but they were able to adjust planting and harvesting times in response to the onset and offset of rainfall. However, coffee farmers were able to change varieties, depending on expectations of rainfall duration. When rainfall was expected to be longer, farmers preferred the long maturity and high yielding varieties, while preference for drought resistance and short maturity varieties was common when shortfalls in rainfall were expected.

A positive significant relationship between coffee farmers and shifting crops (Table 11) indicated that coffee farmers had better access to rainfall forecast and acceptability. Farmers with such access keep changing their main crops depending on the rainfall expectations. Lobell *et al*., (2008) suggested shifting maize to sorghum and vice versa because of the higher tolerance of sorghum to drought. For farmers with similar farm profiles and who are limited to other options, intercropping could be the option for adapting the stresses. Food crop farmers were, therefore, found to intercrop maize with beans, compared to coffee farmers.

Livestock management choices

Livestock management choices are the strategies used by farm households to cope up their livestock to the changes. Farmers shift from one type of feed to another based on availability and reduce herd to the manageable size (Table 11). We explored that 56% and 35% of the coffee and food crop farmers practiced shifting feeds. Optionally, livestock feed is available at veterinary service shops and farmers use in time of shortage. Regarding herd size, only a small fraction of the coffee

(23%) and food crops (17%) farmers reduce the stocking of cows due to most farmers had quite small number of cows (Table 11).

Livelihood options

Enterprise diversification (e.g., crop-livestock diversification and combination of farm with non-farm activities) were other strategies used by many farmers to minimize risks and improve revenue. Combined farm-of farm activities were mainly undertaken by coffee farmers, while temporarily or permanent migration was a means of livelihood for a significant number of farmers in the food crops zone (Table 11). Similarly, results by Barnett & Chamberlain(2002) explored temporary migration as adaptation strategies to climate change through asset building.

Table 11: Current choices of coffee and food crop farmers in the study area

Innovation choices adopted	Coffee farmers		Food crop		t- value
Crop management	Mean	SD	Mean	SD	
Variety change	0.55	0.502	0.12	0.324	5.622***
Adjusting planting dates	0.32	0.497	0.55	0.502	-1.462**
Intercropping	0.38	0.490	0.48	0.504	-1.102
Shifting crops between land types	0.37	0.486	0.12	0.324	3.316***
Diseases control	0.58	0.497	0.12	0.324	6.093***
Livestock management					
Shifting in feeding strategy	0.56	0.502	0.35	0.481	2.114**
Stocking rate	0.23	0.427	0.17	0.376	0.908
Input and resource management					
Tree planting	0.23	0.427	0.53	0.503	-3.523***
Mulching practices	0.28	0.454	0.18	0.390	1.293
Irrigation infrastructure	0.38	0.490	0.40	0.494	-0.185
Livelihood options					
Mix of crops and animals	0.53	0.503	0.43	0.500	1.092
Farm-offarm combination	0.45	0.534	0.22	0.415	2.670***
Temporary migration	0.08	0.334	0.20	0.403	-1.725**

Number of observation (n=159)

*, ** and ***Indicates statistical significance at 10%, 5% and 1% level respectively. Mean in the above Table refers to the mean of the farmers adopted the current choices. The t-statistic compares the inequality of adoption across groups.

Source: Survey data, 2014

So far, the study compared the adaptation choices of farmers from coffee and food crop. The second point was to understand if farmers who perceived the climate has been changing and farmers who do not perceive any change made similar choices.

This proves if the choices were for responding to the changing climate or other determinants. Significant difference is found among farmers in the coffee zone who perceived the climate has been changed and farmers who do not perceived any change in adoption of choices, while no significant difference is found between farmers from the food crop zone who perceive the climate has been changed and farmers who do not perceived any change (Table 12). The results explored that climate change perceived farmers adopted more choices compared to those none perceived farmers. However, this is not an exclusive conclusion. farmers from the coffee zone perceived changes in the long term climate, essentially change the varieties depending on the expectation of the rainfall durations, adjust planting and harvesting time fitting them with the onset and offset of rainfall, look for alternative income sources such as mixed farming of crops and livestock (Table 12).

Table 12: Current choices of adaptation and farmers' perception of climate change in the study area

Current choices	Coffee farmers					Food crops farmers					All farmers				t-value
	Change perceived		Change not perceived		t-value	Change perceived		Change not perceived		t-value	Change perceived		Change not perceived		
	Mean	SD	mean	SD		mean	SD	mean	SD		mean	SD	mean	SD	
Crop Management															
Variety change	0.62	0.49	0.13	0.33	**2.708*** **	0.10	0.31	0.50	0.71	**-1.732***	0.35	0.48	0.20	0.41	**1.115***
Adjusting planting dates	0.48	0.51	0.00	0.00	**2.676** **	0.55	0.50	0.50	0.71	**0.142**	0.52	0.50	0.10	0.30	**6.419*****
Intercropping	0.35	0.48	0.63	0.52	**-1.514**	0.48	0.50	0.50	0.71	**-0.047**	0.42	0.50	0.55	0.52	**-0.783**
Shifting crops	0.42	0.50	0.00	0.00	**2.381** **	0.12	0.33	0.00	0.00	**0.515**	0.27	0.44	0.00	0.00	**3.980****
Diseases control	0.67	0.47	0.00	0.00	**3.990*** **	0.12	0.33	0.00	0.00	**0.515**	0.39	0.49	0.00	0.00	**2.464*****
Livestock management															
Shifting in feeding	0.46	0.50	0.38	0.52	**0.451**	0.34	0.48	0.50	0.71	**-0.446**	0.40	0.50	0.40	0.51	**0.000**
Stocking rate	0.27	0.50	0.00	0.00	**1.688***	0.17	0.38	0.00	0.00	**0.635**	0.22	0.42	0.00	0.00	**1.748***
Access Input and resources management															
Tree planting	0.25	0.44	0.13	0.33	**0.671**	0.55	0.50	0.00	0.00	**1.543**	0.41	0.49	0.09	0.30	**1.939***
Mulching	0.29	0.46	0.25	0.46	**0.221**	0.17	0.38	0.50	0.71	**-1.171**	0.23	0.42	0.27	0.47	**-0.517**
Irrigation	0.40	0.50	0.25	0.46	**0.023**	0.40	0.49	0.50	0.71	**-0.289**	0.59	0.49	0.16	0.50	**2.198****
Livelihood options															
Mixed crop and livestock	0.58	0.50	0.25	0.46	**1.704***	0.43	0.50	0.50	0.71	**-0.790**	0.50	0.50	0.27	0.47	**3.468****
Farm-offarm combination	0.46	0.54	0.38	0.52	**0.423**	0.21	0.41	0.50	0.71	**-0.981**	0.33	0.49	0.36	0.50	**-0.214**
Temporary migration	0.08	0.33	0.13	0.33	**-0.376**	0.19	0.39	0.50	0.71	**-1.071**	0.14	0.37	0.18	0.41	**-0.373**

The Table summarizes a scale measurement of the households perceived and not perceived climate change and adoption of choices (n=159).
*,**,*** Indicates statistical significance at 10 % , 5% and 1% level respectively.
Source: Survey data, 2014

4.4.3. Current economic pressure on the farm; implications of the choices on household income

Farmers' choices on adoption of given adaptation could have two purposes; either for expected profit or avoiding risk. Evidence from Arslan *et al*., (2014) revealed that adoption of climate smart strategies enhances maize productivity and then improves farmers' income in Zambia. Similar to this, adopters of any adaptation strategy in this study were found to be better off than were the non-adopters, showing higher income in all cases. Non-adopters of adaptation strategies were found to have less annual income, by 665.56 US Dollars (USD), compared to adopters of a strategy (Figure 17). This is when compared with the strategy with a minimum return of 1,410.78 USD from a combined adoption of improved varieties and irrigation (VARIRR). The comparison between the adoptions of single choice also revealed that irrigation adoption yields higher income, followed by varietal change and mixed crop-livestock diversification, respectively. Farmers adopting all three choices of crop-livestock diversification, variety change, and irrigation (MIXVARIRR) had better income than did single strategy adopters; for instance, their annual income was 3,574.24 and 3,157.59 USD greater than were those of crop-livestock and irrigation adopters respectively (Figure 17). The comparison also revealed that, although choices of in combination and separate strategy have significant and positive effects on household income, adoption of a combination of packages benefit farmers more than adoption of a single strategy. Similar results are reported by Teklewold *et al.,* (2013), in Ethiopia, for an analysis of maize-legume rotation, conservation tillage, and modern maize seed and four combinations of the three key variables.

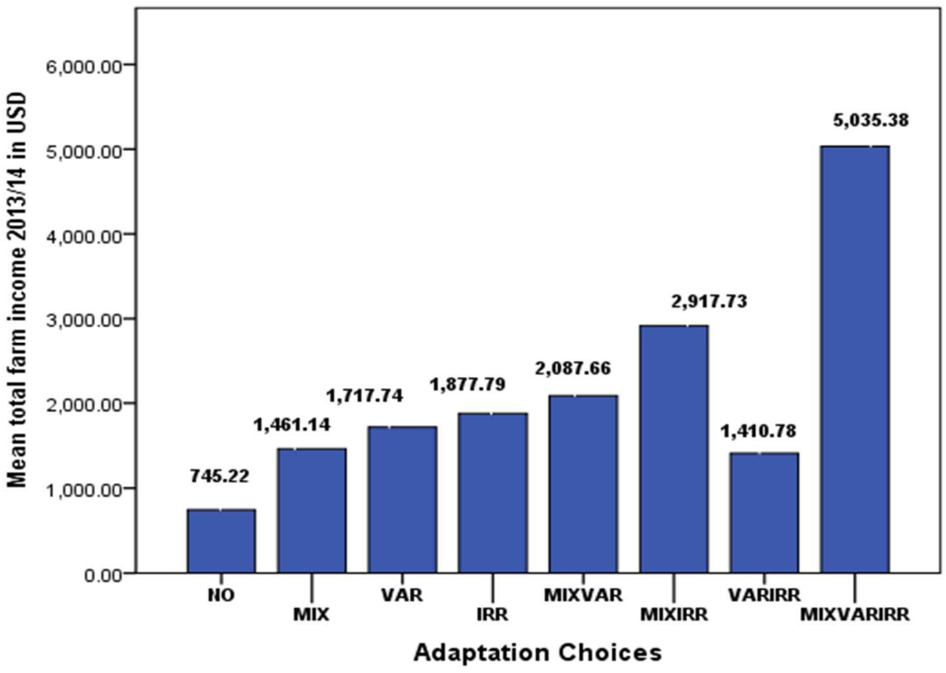


Figure 17: Implication of current choices on household farm income. The figures left of the diagram represent annual income in USD the lists down of the diagram are the adaptation choices used by farm households.

4.4.4. Determinants of adaptation choices

The parameter estimates from the logit regression on the determinants of adaptation choices and the marginal effect are presented in Table 13 and 14, respectively. Households with higher family size are likely to choose irrigation (IRR) strategies and variety change and irrigation (VARIRR). This could be in relation to the labour availability as most of the choices were labour intensive. Better educated farmers were found more likely to choose crop-livestock diversification, variety change and irrigation (MIXVARIRR) in combination, while a unit increase in education level of the household head (in years of education) increases the probability of choosing crop-livestock diversification, variety change and irrigation (MIXVARIRR) by 1.89 %.

Farm income was highly related to the choice of all the packages. 100 USD increase in household total annual farm income was found to increase the households' choices of crop-livestock diversification (MIX), variety change (VAR), irrigation (IRR), variety change and irrigation (VARIRR), and crop-livestock diversification, variety change and irrigation (MIXVARIRR) by a factor of 3.4%, 1.3%, 3.5%, 5.3%, and 7.4 %, respectively. This might be due to the fact that higher income farmers had better access to technologies and services. Choice of combinations of adaptation strategies was higher for farmers with better income through developing the capacity to breakdown the capital constraint to invest in adopting new technologies (Teklewold *et al*., 2013). Being a farmers from the coffee zone was found to be positively correlated with choices such as variety change (VAR), and crop-livestock diversification and variety change (MIXVAR), while it was negatively linked with irrigation (IRR). This was found to increase the probability of choosing variety change (VAR) and crop-livestock diversification and variety change (MIXVAR) by 43.03%, and 34.62%, respectively. However, an opposite sign and similar magnitude was observed with farmers from the food crop zone (Table 13 and 14).

Table 13: Parameter estimates of the determinants of adaptation choices

Variables	MIX	VAR	IRR	MIXVAR	MIXIRR	VARIRR	MIXVARIRR
	Coef.	Coef.	Coef.	Coef.	Coef.	Coef.	Coef.
GENDER	0.18	2.14	-0.86	1.01	1.33	-1.18	28.94
	(1.07)	(1.31)	(1.17)	(0.91)	(1.16)	(1.19)	(153)
FAM	0.61	0.30	0.34**	0.20	0.37	0.56*	0.64
	(0.43)	(0.36)	(0.36)	(0.34)	(0.48)	(0.32)	(0.64)
HHHEDU	0.01	-0.01	0.15	0.05	0.05	-0.15	0.71*
	(0.19)	(0.14)	(0.19)	(0.13)	(0.16)	(0.40)	(0.46)
FARMSIZE	-0.41	0.24	-0.24	0.08	0.53*	-0.68*	0.04
	(0.51)	(0.36)	(0.35)	(0.26)	(0.31)	(0.40)	(0.49)
INCOMEFARM	3.1e	0.00**	0.00***	0.00**	0.00**	0.00**	0.00***
	(5.8e)	(6.1e)	(5.9e)	(5.8e)	(5.7e)	(6.1e)	(6.2e)
OFFARMINC	-0.00	5.2e-	6.1e	2.5e-	7.7e**	2.2e-	3.4e***
	(8.3e-)	(4.6e)	(3.8e)	(3.7e)	(3.9e)	(5.1e-)	(5.2e)
TLU	0.56	-0.29	0.80	0.24	0.11	0.36	1.07
	(0.83)	(0.61)	(0.61)	(0.49)	(0.61)	(0.61)	(1.09)
DISTANCE	-0.49*	0.10	0.58**	0.41	20.22	-0.05	-0.41
	(0.26)	(0.18)	(0.23)	(0.16)	(534)	(0.18)	(0.59)
CREDIT	3.24**	0.27**	1.59	2.40**	0.61	1.17	21.09
	(1.6)	(1.09)	(1.34)	(1.22)	(1.33)	(1.19-)	(977)
EXTENSION	3.57*	1.04	1.60	1.87*	0.03	2.18	3.72**
	(1.84)	(1.21)	(1.21)	(1.03)	(0.18)	(1.56)	(1.86)
INFORMAT	-0.18	0.80	1.91	0.33*	1.15	3.63***	3.33
	(1.38)	(1.05)	(1.20)	(0.94)	(1.13)	(1.3)	(2.65)
TRADKNOW	1.35	1.31	-0.64	1.19	-15.87	0.56	0.17
	(1.06)	(0.99)	(1.10)	(0.87)	(647)	(0.96)	(2.38)
PERCEPTION	-3.11*	1.06	1.05	3.39**	-0.01	1.27	5.72
	(1.86)	(1.53)	(1.92)	(1.92)	(1.13)	(2.17)	(3.80)
INNOVATIVE	-1.37	4.65**	-15.80	4.25**	3.21	2.92	-1.33
	(2.46)	(2.12)	(629)	(1.75)	(1.64)	(2.08)	(3.74)
MANURE	1.51	-0.85	1.12	-0.11	1.26	-3.09*	2.93
	(1.24)	(1.44)	(1.26)	(1.04)	(1.26)	(1.75)	(2.40)
MULCHING	0.09	-0.33	-2.14	0.15	-0.07	-2.93**	-1.34
	(1.32)	(1.25)	(1.81)	(0.98)	(1.37)	(1.4)	(2.64)
COMPOST	2.43	-2.52**	-4.01*	-2.31*	-1.87	-1.80	5.03
	(1.56)	(50)	(2.08)	(1.33)	(1.69)	(1.85)	(3.93)
COFFEE(Base Food crop)	0.57	2.97**	-0.24*	23.31***	-0.23	-1.48	0.34
	(1.50)	(1.44)	(1.34)	(35)	(1.44)	(1.52)	(1.86)
FOODCROP(Base Coffee)	-0.57	-2.97**	0.24*	-23.31***	0.24	1.48	-0.34
	(1.51)	(1.4)	(1.34)	(35)	(1.44)	(1.52)	(1.86)
CONSTANT	1.36	-6.04**	-9.82***	-1.51***	-29.46	-0.37	-75.38
	(2.99)	(2.7)	(3.6)	(3.5)	(5.34)	(3.04)	(18.92)

Base category= NO; Number of observations (n =220); log likelihood= -131.62; LR $\chi2$= 212.27; prob. χ^2=0.0000; pseudo R^2=0.4464
*,**,***Indicates statistical significance at 10%, 5% and 1% level respectively.

Table 14: Marginal effect from the Multinomial logit model of farm level adaptation measures

Variables	MIX	VAR	IRR	MIXVAR	MIXIRR	VARIRR	MIXVARIRR
GENDER	0.1339	0.1024	-0.1184	0.1027	0.1823	-0.0762	0.0975
FAM	0.0423	0.0048	0.0316	0.0028	0.0013	0.0201	0.0216
HHHEDU	0.0262	-0.0127	0.0013	0.0183	0.0087	-0. 0070	0.0189
FARMSIZE	-0.0135	0.0049	-0.0109	0.0080	0.0304	-0.00863	0.0040
INCOMEFARM	0.00026	0.0037	0.0048	0.0019	0.0016	0.00019	0.00015
OFFARMINC	-0.00034	0.00013	0.00014	0.00035	0.00053	9.26e-06	0.000748
TLU	0.0320	-0.0231	0.0538	0.0112	0.0168	0.0136	0.0279
DISTANCE	-0.0051	0.0115	0.0163	0.0282	0.0060	-0.0023	-0.0085
CREDIT	0.0630	0.2587	0.1516	0.1885	0.0237	0.1659	0.0674
EXTENSION	0.0408	0.0458	0.0920	0.1078	0.1400	0.0355	0.0315
INFORMAT	-0.1329	0.1174	0.1642	0.041	0.0412	0.2047	0.0877
TRADKNOW	0.0810	0.0611	-0.0055	0.0052	-0.0048	0.0292	0.1355
PERCEPTION	-0.1405	0.0993	0.0303	0.2155	-0.084	0.0257	0.0103
INNOVATIVE	-0.1656	0.1026	-0.0134	0.1737	0.0421	0.0320	-0.0597
MANURE	0.1438	-0.0904	0.1549	-0.029	0.1345	-0.0775	0.1680
MULCHING	0.0599	-0.0093	-0.1109	0.0232	-0.0475	-0.1055	-0.0278
COMPOST	0.1782	-0.1595	-0.0119	-0.0185	-0.0987	-0.0203	0.0592
COFFEE(Base Food crop)	0.1664	0.4303	-0.2625	0.3462	-0.120	-0.0485	0.1417
FOODCROP(Base Coffee)	-0. .1664	-0.4302	0.2625	-0.346	0.1201	0.0485	-0.1417

Base category= NO; Number of observations(n =220)
*,**, ***Indicates statistical significance at 10%, 5% and 1% level respectively.
Source: Survey data, 2014

Farm size was found positively correlated with crop-livestock diversification and irrigation (MIXIRR), while it was negatively correlated with variety change and irrigation (VARIRR); an increase in unit acre of land ownership of the household was linked with a probability of choice to crop-livestock diversification and irrigation (MIXIRR) at 3.04 %. This emphasises that smallholder farmers were likely to invest in irrigation strategy and to change their variety for compensation of small farm size by intensified production whereas large holder farmers tended to rely on crop-livestock diversification and irrigation (MIXIRR), due to the requirement of space for the animals and irrigated crops' production. Institutional variables (access to credit and extension services) had a positive impact on the adoption of choices, such as crop-livestock diversification (MIX) and crop-livestock diversification and variety change (MIXVAR). This was found similar with previous results such as Yegbemey *et al.*, 2014. A household's access to credit was found to increase the household's probability of choosing crop-livestock diversification (MIX), variety change (VAR), and crop livestock diversification and variety change (MIXVAR) by 6.30%, 25.87%, and 18.85%, respectively, while an access to extension had a probability of choosing for crop-livestock diversification (MIX), crop livestock diversification and variety change (MIXVAR), and crop livestock diversification, variety change and irrigation (MIXVARIRR) by 4.08%, 10.78%, and 3.15%, respectively (Table 13 and 14). Farmers perceiving that the climate is changing negatively were likely to adopt a crop-livestock diversification and irrigation (MIXIRR), while avoiding crop-livestock diversification (MIX). Farmers perceiving that the climate is either changing positively or not at all were linked to the crop-livestock diversification (MIX) option at a probability level of 14.5%. Farmers' innovativeness was found to have a strong positive relationship with variety change (VAR) and crop-livestock diversification and variety change (MIXVAR). Innovative farmers were likely to adopt variety change (VAR) and crop-livestock diversification and variety change (MIXVAR), at probability levels of 10.26% and 17.37%, respectively.

4.5. Discussion and conclusions

The results of this study have some limitations. The adaptation strategies in this study are limited to exhaustively on-farm choices derived from the survey. However, in the context of climate change, other strategies, such as new infrastructure, subsidies, voluntary market solutions or changes in the sectoral activity, are likely to determine the adaptation process. Future research is, therefore, needed to further understand the underlying pull and push factors that define farmers' choices and the determinants of choices in a wider scope of policy influence, infrastructure and market performance.

Despite these limitations, the results of this study contribute to the body of knowledge on adaptation choices, and determinants that provide information for local policy decisions. Farmers from the coffee zone who perceived the climate is changing adopt more choices than farmers who perceive no change, while there is no significant difference among farmers from the food crop zone who either do or do not perceive changes. Perceptions may be in relation to current pressures and impacts, while adaptation requires elements beyond perception, such as education, information, assets and resources, institutions, and infrastructures. Macro studies, such as the IPCC fifth assessment dominantly emphasis on adaptation and mitigation interactions basically on regional levels (IPCC, 2014) micro studies, so far, are limited to the conclusion that only farmers who perceive climate change respond to the changes by considering a series of adaptation strategies (Abid *et al*., 2015; Maddison 2007; Bryan *et al*., 2009; Deressa *et al*., 2008). However, farmers are found to adopt adaptation strategies in response to other factors beyond climate perception such as economic and social pressures.

Farmers from the coffee and food crop zones are found to respond to the changing climate differently. However, literature that comparing choices between farmers from the coffee and food crop zones is insufficient. Studies from Central America and Mexico (Tucker *et al*., 2010) claims different adaptation choices for farmers from the coffee zone, and other studies such as Bryan *et al.,* (2013), Nhemachena & Rashid, (2008), Lin (2011), describe adaptation choices to climate change pertinent to farmers from the food crop zone. Though these discrete studies were conducted separately, at different locations, we found that researches done on coffee and food crops showed similar results. Choice of crop types, improved farm inputs management, diseases control, crop-livestock diversification, and controlling of stocking rate of livestock were mostly used by farmers from the coffee zone, while adaptation choices, such as tree planting, irrigation supplementation, intercropping, adjusting planting and harvesting dates in response to rainfall onset and offset, and permanent or temporary migration were mostly adopted by farmers from the food crop zone.

Our results on the likelihood of choices of adaptation confirm results from previous studies. Family size was found to determine adoption choices, such as irrigation which is similar to results from Abid *et al*., (2015); Deressa *et al*., (2009), while education of the household head was found to be positively correlated with crop-livestock diversification, variety change and irrigation (MIXVARIRR). Household farm income was found to determine all the choices of adaptation positively. Similar studies, such as Deressa *et al*., (2009), find that farm income positively affects choice of irrigation and variety.

Access to credit was associated to crop-livestock diversification (MIX), variety change (VAR), and crop-livestock diversification and variety change (MIXVAR), where similar studies, such as Tekelewold *et al.,* (2013) and Yegbemey *et al*., 2014 find a similar result. The analysis of the adaptation choices in this study considered both farmers who perceived climate change and farmers who did not perceive climate change. A significant portion of the farmers who did not perceive a change was found to be using some adaptation strategies.This could be due to economic factors, such as income or other drivers, and it disproves the conclusion that farmers adopt adaptation choices if, and only if, they perceive changes. The strong correlation between the socio-institutional variables and choice of adaptation strategies suggests the need for the establishment and strengthening of local institutions, such as micro-finance and extension institutions. These institutions have the capacity to break the capital constraint of farmers to invest through provision of credit and advisory services.

CHAPTER FIVE
THE ROLE OF SYSTEMS OF INNOVATION TO BRING NEW FRONTIER OF ADAPTATION TO CLIMATE CHANGE: EVIDENCE FROM THE KENYAN COFFEE AND DAIRY SECTOR

5. THE ROLE OF SYSTEM OF INNOVATION TO BRING NEW FRONTIER OF ADAPTATION TO CLIMATE CHANGE: EVIDENCE FROM THE KENYAN COFFEE AND DAIRY SECTOR

Kinfe Asayehegn, Ana Iglesias, Bernard Triomphe, Philippe Pedelahore, Ludovic Temple

Abstract

Researches on sectoral systems of innovation have typically been focused on the industrial sector and the framework has not been mobilized to analyze climate change adaptation in agriculture. This article, therefore, explores the roles of systems of innovation in driving options to adapt to climate change, which claims sectoral innovation performance depends on the performance of institutions and actors interaction. The research is based on two case studies, i.e., coffee and dairy sectors that are different in terms of actors involved, and institutional setup. The results finds that in the coffee sector, actors system is highly centralized and the system of innovation is dominantly on technology development. In contrary to the coffee, many actors make-up the dairy sector, which is informally controlled by demand based business and the system of innovation is mostly on institutional building. The capacity to innovate, therefore, depends on the institutional element in addition to its technology development.

Keywords: Climate change, Coffee sector, Dairy sector, System of innovation, Central Kenya

Résumé

Sur de nombreuses études conduites sur les systèmes sectoriels d'innovations sur le secteur industriel, et rares sont celles appliquent ce concept dans l'analyse d'adaptation au changement climatique en agriculture. Cette étude explore donc le rôle des systèmes sectoriels d'innovations en tant que levier d'adaptation au changement climatique, dont la performance des systèmes d'innovations sectoriels dépend de l'interaction entre les acteurs et institutions. Cette recherche est basée donc sur deux études de cas, i.e. les filières café et lait qui sont différentes en termes de configuration institutionnelle et de typologie d'acteurs. Les résultats de l'étude montrent que, le système d'acteurs est largement centralisé, avec dominance de l'approche développement de technologie comme système d'innovation. Contrairement au café, le secteur laitier est composé de nombreux acteurs, et contrôlé de manière informelle par les entreprises privées basées sur la demande, avec un système d'innovation axé principalement sur le renforcement de capacité institutionnel. La capacité d'innover dépend donc de l'élément institutionnel en plus de son développement technologique.

Mots clés: Changement climatique, filière café, filière lait, Système d'innovation, Kenya central

Resumen

Las investigaciones sobre los sistemas sectoriales de innovación se han centrado típicamente en el sector industrial y el marco no se ha movilizado para analizar la adaptación al cambio climático en la agricultura. Este artículo, por lo tanto, explora los roles de los sistemas de innovación en la conducción de las opciones para adaptarse al cambio climático, que afirma rendimiento de la innovación sectorial depende del rendimiento de las instituciones y los actores interacción. El estudio tiñe logar en la región central de Kenia. La investigación se basa en dos estudios de caso, es decir, los sectores de café y lácteos que son diferentes en cuanto a los actores involucrados, y la configuración institucional. Los resultados revelan que en el sector cafetalero, el sistema de actores está altamente centralizado y el sistema de innovación está predominantemente en el desarrollo tecnológico. A diferencia del café, muchos actores componen el sector lácteo, que es informalmente controlado por el la competitividad económica basada en la demanda y el sistema de innovación se basa principalmente en la construcción institucional. La capacidad de innovación, por lo tanto, depende del elemento institucional además de su desarrollo tecnológico.

Palabras clave: Cambio climático, Sector cafetalero, Sector lácteo, Sistema de innovación, Kenia Central

5.1. Introduction

The argument on the impacts of climate change on economic growth is under debate. Some finds climate change is potential for economic growth, while others argue it as a reason for slow-growth economy or even de-growth. Studies on regional differences explored that in the Northern hemisphere cold regions, climate change could have positive effect on production, while in the tropical, climate change is expected to substantially reduce economic growth through negative impact on agriculture and aggregate investment (IPCC, 2014). For instance, in Africa and Latin America, maize production is expected to decline in relation to climate change which would be a cause for the loss of $2 billion per year as of 2055 compared to the current production (Jones & Thornton, 2009).

These impacts will be more important as the Green House Gas (GHG) emission will be higher. However, in all cases adaptation strategies are necessary. Decisions on adaptations need to take into account the ever changing climate because of two main reasons. First, future uncertainty challenges the use of available technologies as they are designed for current challenges (Iglesias *et al*., 2011), and second, the rate of climate change calling for flexibility in new infrastructural development (Hallegatte, 2009). Impacts also vary with agricultural systems (Touzard, 2015; Touzard *et al*., 2015), where systems differ in sensitivity and exposure to changes.

The adaptation capacity to the changes depends on the market dynamics of products and capacity of the different actors (Schroth *et al*., 2009). Touzard (2015), for instance, reports climate change directly or indirectly affects vineyard value chain including firms and actors in the supply chain beyond its direct impacts on wine producer's income. Hence, adaptation capacities depend on the type of sectors, actors' interaction and coordination. In the rainfed crops production, adaptation comprises practices, such as adopting drought resistant varieties (Teucher *et al.,* 2016), or intercropping of different crops (Lobell *et al.* 2008), while changing breeds (Seo, 2010), and alternative feeding strategies (Herrero *et al.* 2014) are common in the livestock sector. In a mixed crop-livestock production potential areas, an integrated farm is more resilient (Seo, 2010), while livestock production could be the only option in marginal areas to crop production (Jones & Thornton 2009).

Innovation studies so far emphasises on the roles of innovation to bring economic and social change (Van Lancker *et al.,* 2016; Temple *et al*., 2015; Aghion *et al*. 2014). Malerba, (2002) identified knowledge and technology bases, demand structure, and firm characteristics are different across sectors. Competitive performance within sectors depends on institutional arrangements dedicated to research and innovation, intensity of R&D investment and regional institutional arrangement (Boyer, 2016). The empirical studies so far are, however, insufficiently taken in to account the sectoral differences in climate change adaptation. This article was, therefore, aimed at analysing the roles of systems of innovation to adapt to climate change the case of coffee and dairy sectors in Central Kenya. This basically provides an answer to the questions such as: - what characteristics of the systems of innovation are particular to each sector in the adaptation process to climate change? And how these characteristics of the innovation affect the adaptation process and competitiveness of the sectors?

In this article, we mobilized the sectoral systems of innovation framework due to different reasons. First, the study compares coffee and dairy sectors which are similar in terms of farmers' objectives and shifting historical fortunes, but are different in terms of marketing, socio-political and technical characteristics and policy. Second, the interest to contribute to the sectoral system of innovation literature from the sectors other than industrial. And third, to bring an insight on the sectoral differences in adaptation to climate change. The next section discus the concepts and present theoretical frame. In section three, we present the methods. In section four we present the results and finally, in section five, we present the discussion and concluding remarks.

5.2. Sectoral Systems of Innovation Approach; Innovation to Adapt to Climate Change

Innovation processes are human adaptations to changing needs and socio-economic conditions (Rodima-Taylor *et al*. 2012; Edquist, 2001), which is concerned with the search for and discovery, trial and experimentation, production and adoption of new knowledge (Hartwich and Negro, 2010). This concept as explained in Smits and Kuhlmann, 2004 is a successful combinations of hardware, software, and orgware. More specifically, Freeman (1989), argues that innovation involves learning agents and their interdependencies, institutions and policies that govern action. This innovqtion, which involves the actors and their institutions could be undertaken at global, national, local, or sectoral levels. At global or national level, the national system of innovation focuses on national boundaries and non-firms organizations and institutions (Freeman, 1989: Lundvall, 1993), while the meso level regional systems of innovation focuses on regions (Cooke *et al*., 1997). In sectoral systems of innovation on another way, the focus is mainly on specific sectors (Malerba, 2002; Edquist and Chaminade, 2006), such as agriculture, dairy, industry or forest systems. Current research on system of innovation are mainly oriented towards the macro and meso level of national and regional systems of innovation (Van Lancker *et al.,* 2016). The sectoral level of innovation, particular to sectors such as agriculture however, has received very little attention with in the innovation system perspective.

The concept sectoral system of innovation (Malerba, 2007; Malerba, 2004; Malerba, 2002; Edquist and Chaminade, 2006; Breschi *et al*., 2003), which basically provides a multi-dimensional, integrated and dynamic views of sectors in general is stated as the set of products and the set of agents or actors carrying out market and non-market actions. The products are the specific knowledge and learning process, basic technologies, demand, or inputs, while the agents in the sectoral system of innovation are the individuals, firms and non-firm organizations or institutions, who are involved at various levels of the innovation process (Malerba, 2007; Malerba, 2002). These actors have a specific models of interaction, interdependencies and links, which is dependent on the nature their structure is organized.

Although sectors provide a key level of analysis (Edquist, 2001) for economists and technological innovationists in a multi-dimensional way, Malerba 2002 identified two main traditions dealing with sectoral system of innovation. These are the traditions in the industrial economics literature and econometric industry studies, where basically the two studies are part of the evolutionary economics and interactive learning. These studies have examined the structure of sectors in terms of concentration, vertical integration, diversification, firms' growth and the inter-action among them (Malerba, 2002; Malerba *et al.,* 1997; Breschi *et al*, 2003). The framework of sectoral system of innovation, so far, has not been mobilized to analyze different sectors, such as climate change adaptation strategies in agriculture and other sectors, rather than characterizing the sectoral dynamism and firm technological diversification, particularly in the industrial sector. In agriculture, the concept of system of innovation to adapt to climate change refers to two approaches notably the innovation towards technological development termed as the science, technology and innovation (Berg *et al.* 2007), and the innovation towards enabling business environment, such as market systems, and infrastructural development (Klerkx & Jansen, 2010; Meynard *et al,* 2016).

This article, therefore, makes initial search developing a framework to link the concept of sectoral system of innovation and its application in how do coffee and dairy systems adapt to climate change and how do actors interact in the innovation process to adapt to climate change of the two systems. We mobilize the application of systems of innovation to the different sectors believing that the two systems have different actors and institutional characteristics. This primarily assumed performance of sectors and their capacity to adapt to climate change depends on the actors and institutions make up the system. It is in the evolutionary theory, key concepts, such as learning, knowledge and competence are present, while the relationships, networks and interactions among sectors and actors are part of the innovation systems literature (Malerba, 2002). This links sectoral differences to adapt to climate change to the concept of evolutionary theory and systems approach. In relation to this, our article considers different theoretical background.

The first dimension we have to consider in building the theoretical framework is the understanding of the sectoral changes and transformation, which are undertaken at different laws of motion, dynamics, and emergency (Malerba, 2002; Edquist and Hommen, 1999). These sectors changes, which happens overtime could be due to the impacts of climate change, or some other reasons. Factors of change, other than the external force could be the evolutionary life cycle of the sectors (Utterback, 1994; Klepper, 1996), or the economic interest of actors (Hallegatte, 2009). But the external force related to climate change impacts is one of the theories under impact pathways. This pathway includes impact pathway and adaptation pathway. From the impact pathway context, climate variability and change may increase the frequency of drought and thus impacts the innovation to adapt to changes (Figure 18). Due to the direct relationship between crop production and climate, agriculture is the sector most affected by climate change (Howden *et al*., 2007; Angeon and Bates, 2015). Hence, the link between impacts of climate change on the sectors and innovation in the new frontier to adaptation to climate change explores climate change impacts the sectors directly (Figure18) through shifting climatic controls, and indirectly, through changes in agricultural land use system (Hannah *et al*. 2013). In relation to this, suitable areas for agricultural production could become marginal and shifting patterns of agricultural production in response to climate change (Schroth *et al.* 2009). As temperature and rainfall patterns are expected to continue to change, impacts will be more severe and adaptations become compulsory.

The second key element of sectoral system of innovation considered in this article, is a tradition of links and interdependencies between different sectors and actors (Malerba, 2002). The boundaries of sectors consider interdependencies and links among related industries and services and these boundaries are not fixed but dynamic, which provide mechanism of emergence, growth, changes and innovation (Malerba, 2002). Over the last 35 years, coffee in Kenya for instance, have moved up to higher altitudes, while food crops are grown at the altitude once reserved for coffee production (Asayehegn *et al*., 2017). This sector or system level interdependence and link creates a mechanism of interaction among actors. In the coffee agroforestry systems of Kenya, the emergency of the dairy sector became a reason for actors' interaction (Asayehegn *et al*., 2017). This created higher interaction between coffee with tea systems and dairy systems. In such cases, links and boundaries could be in a competitive or supplemental advantage. The links and interdependencies among actors could be among actors within a sector and/or across sectors. This leads to a third key dimension, innovation and adaptation process, which could be a circular process.

The innovations to adapt to climate change includes technological (Bergek *et al*., 2008), such as the development of new varieties and new breeds, or institutional (Van Lancker *et al.,* 2008), which is the process of collaboration among actors reduces the impacts (Figure18). Empirical studies show, technological innovations in agriculture have enabled farmers to adequately adapt to climatic challenges. The development of new cultivar of cowpea in the Sahelian West Africa, for instance, helped farmers to cope up with the experienced climate challenges (Chhetri *et al.* 2012). In East and Southern Africa, scientists have developed high yielding maize varieties for farmers' food security. With the objective of reducing vulnerability to drought, the project Drought Tolerant Maize for Africa (DTMA) has tested 160 maize varieties and release these varieties to farmers between the years 2007 and 2013 (Fisher *et al.,* 2015) which helps the region one step forward in the innovation process to food security. The crop variety development which is a key determinant for production enhancement has to be supported by agronomic practices and these agronomic practices are as important as the new varieties. Comparative analysis of adoption of multiple and single sustainable adaptation practices, such as cropping system diversification, conservation tillage and nitrogen fertilizer use in Ethiopia finds adoption of sustainable adaptation practices increases maize income and the highest payoff is achieves when sustainable adaptation practices are adopted in combination than in isolation (Teklewold *et al.* 2013).

On another way, Institutions, such as market where the organizations operate to disseminate the technological innovations may exert influence on both the impacts of climate change and the process of climate change adaptation (Figure 18). For example, adoption of new varieties depends on the profitability of coffee and the impacts to the households may be smoothed using technological and institutional innovations. Similar to the coffee sector, adoption of technological innovations at the dairy sector (new breeds, feeding strategies) depend on access to market. Some innovations may also take us back to new forms of impacts, which may be difficult to adapt with the current strategies (Figure 18). Actors' interaction determine in bringing solution to the circular process of cause-effect relationship. In connection to this, Dyer & Singh (2012) identified knowledge sharing and inter-organizational learning, complementary resource development and capacity, and effective governance are crucial for adaptation. The exclusion of farmers and their institutions such as farmers' federations, in technology development particularly production and management technologies hinders the performance of technological innovation (Cerdán *et al.*, 2012). This implies institutional innovation towards management decisions and practices maintains the capacity to adapt to climate change. A study from the dairy sector in Kenya for instance, explores that farmers' innovation need the development of new technologies and information, better support services for input access and infrastructural facilities for delivering their products to markets (Schreiber 2002). Cooperative institutions are for instance potential catalyst for cost of production and marketing minimization, stimulate entry to market and promote growth of dairy firms. The performance and efficiency of the sectors, however, depends on the roles and performance of the actors, their interaction and co-production of knowledge (Klerkx & Nettle, 2013)

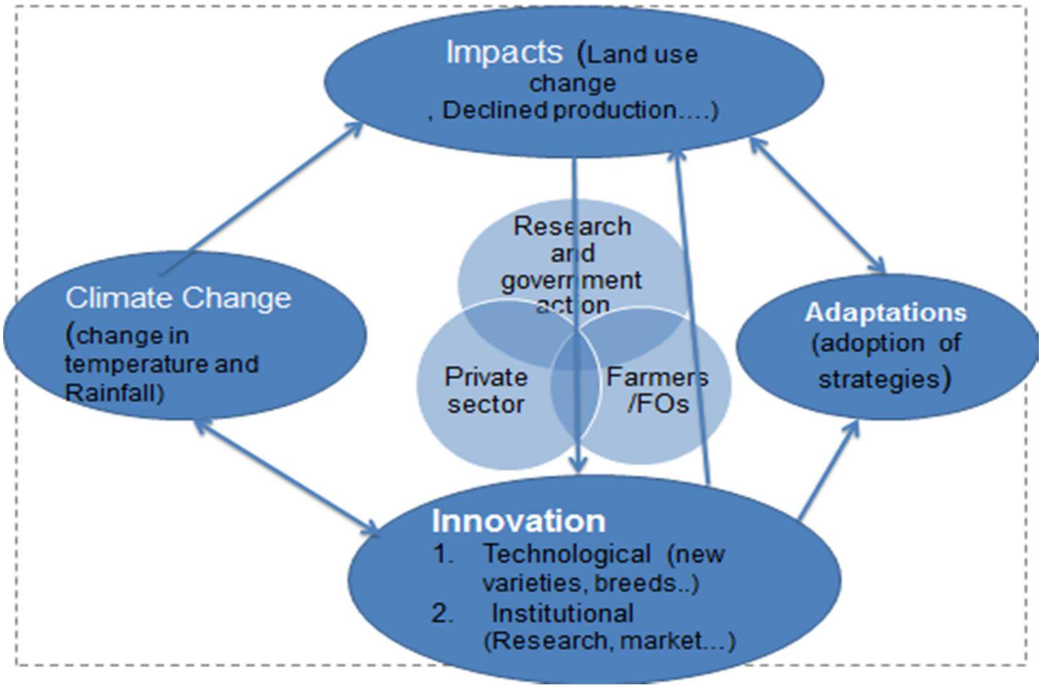


Figure 18: Conceptual model illustrating interaction between climate change impacts, innovations and adaptation to climate change

5.3. Data and Methods

5.3.1. The climate change context and case description

Coffee production was the main subsidiary income generating activity for the rural poor in Kenya (Carsan, 2014). Following to “Lancaster House Conference” after independence, majority of large scale coffee farms were sold to local elites (Ratten, 1993) and local indigenous people were encouraged to invest in coffee. Due to the expansion of plantations and attention to coffee by farmers and government, the sector grew at an annual rate of 6.6% until 1987 (FAO 2013). Since 1988, however, coffee production has declined by 62% (FAO 2013). During this period, the sector has lost its level, where coffee has moved up from the lower altitudes and has been replaced by dairy and food crops. This has two reasons. First, warmer temperatures and erratic rainfall (Asayehegn *et al.* 2017) induced the transformation of potential areas to semi-arid zones, where a unit minimum temperature increase is subjected to a yield decline of 137 kg per hectare (Craparo *et al.,* 2015), and second, the climate change derived infestation of Coffee Leaf Rust (CLR) and Coffee Berry Diseases (CBD) caused transformation of previously potential coffee areas to marginal coffee or food crops (Jaramillo *et al.,* 2014).

The dairy development progress in Kenya had three main periods, i.,e, the period of steady growth (before 1990), disruption (1991-2002), and the period of revival (since 2003) of dairy. During the period of steady growth, indigenous farmers were encouraged to manage improved dairy, attention was shifted towards the growth of smallholder farmers through training, infrastructural development and service delivery. Annual milk production grew from 75.09 million liters in 1964 to 392.32 million liters in 1990. During the period of disruption, dairy production declined. Annual production for instance was declined from 359 million liters in 1991 to less than 150 million liters in 2002 due to the absence of efficient market and supply system. During the period of revival, the dairy sector experienced a sharp increase in volume of production reaching to over 4.1 billion liters in 2014 (FAO 2011).

Farmers’ priorities to either coffee or dairy, however, depend on different reasons. Pinard and Aithal, 2008 explore farmers in Kenya who accorded higher priority on coffee production is in relation to the historic reasoning that coffee was their first cash crop and coffee as a crop is controlled by the men in the household, while women are responsible for livestock and other crops. Initial investment cost determines for the priority of different enterprises, where farmers who have the initial investment cost have the possibility of prioritizing dairy farming as their primary cash crop due to their purchasing power of cows and shed, while others prefer to continue in coffee production due to its lower running cost compare to dairy.

5.3.2. Methodological approach

Data sources

Three types of data were used for this study, *i.e.,* village and household data collected using nine Focus Group Discussions (FGDs) and 240 household surveys (86 coffee specialized, 102 diversified coffee-dairy, and 52 dairy specialized farmers), historical climate data to analyse trends, and stakeholders' survey. The FGDs were conducted with twelve farmers per group and three FGDs per system. FGD members were selected by local leaders after developing different criteria such as farming experience, extent of knowledge about the village, diversity of farming practices, and perception of climate change. An equal number of participants were therefore drawn from each category with the aim to understand the community. We first stratified our sample proportionally to the production systems. We then took random selection to get the first farmer from the list and then we calculated the sampling unit for list of sample farmers. The selection considers three groups: - group one, coffee specialized systems includes households produces coffee at high rate of intensification. Group two, considers coffee-dairy diversification, where either the household's attention is to both systems or households farm income is almost equally from coffee and dairy. Group three, includes dairy specialized systems, where at least 80% of farmers' income is from dairy.

The household survey was conducted via face to face interview during May-October 2015 with heads of households. Farmers were asked about general farm and household characteristics, perceptions of climate change, livelihood means and income types, kinds of innovations they have introduced, where they had obtained necessary information, assistance, material, finance and the contribution of different actors to farming. This helped us to characterize the coffee and dairy farmers and understand how the systems of innovation in the coffee and dairy sectors are organized. Historical meteorological record of temperature (daily minimum and maximum) and rainfall (daily mean rainfall) over 35 years (1981-2014) from representative stations was retrieved from the Kenya Meteorological Department (KMD). Statistical significance was performed using Mann-Kendall test of significance, while the direction and magnitude of the trends was estimated using Sen's slop estimator.

Data about other stakeholders were collected using individual semi-structured interviews with actors of innovation networks, who also shared their own experiences. A total of 23 such interviews were conducted with senior experts, technicians, managers, and heads of the following stakeholders: research, extension, private marketing, processing and input dealers, NGOs and CBOs, ministries: Questions focused on what services each of them provided to farmers, and how they supported farmers . To analyze the contribution of different actors to the development of the sectors, a six scale measure (5=very high contribution, 0= not at all) was developed to analyze the views of farmers and stakeholders towards actors contribution.

5.4. RESULTS

The innovation for adapting to changing climate in this section contemplates two case studies. The innovation to specialize in the coffee sector through technological and institutional innovations such as developing diseases resistance new varieties of coffee, improved agronomic practices and market arrangement in one hand and the technological and institutional innovation towards diversification to dairy or specialized in dairy from a specialized coffee sector and the institutional arrangements.

5.4.1. Technological and institutional innovation: A case from the coffee sector of Central Kenya

Developing disease resistant coffee varieties

Between 1963 and 1987, national coffee production rose dramatically from 34 to 140 metric tonnes. This was due to two technological innovations. In 1963, local farmers were encouraged and supported to use the right input system such as fertilizer and cultural practices such as pruning. This permitted production per unit area to increase. The second technological change was the introduction of chemicals in the mid-1960s to prevent frost, CBD and CLR. Inputs and management supports were from the government directly through the cooperatives. For further improvement of production and quality in 1971, Coffee Research Foundation (CRF) proposed another technological change; developing a new diseases resistance variety. In 1980, the researchers came up with a new variety called "*Ruiru 11*" and released it in 1985.

Despite the technological changes towards developing new varieties, social needs institutional conditions and extension services were inadequately taken into account. This new variety development failed to bring coffee production increase or at least maintain its level. Annual production for example declined from 140 to less than 50 metric tonnes between 1988 and 2011 and production per hectare has reduced from 735 to less than 253 kilograms.

Despite the technological changes towards developing the new varieties, social needs and institutional conditions and extension services were inadequately taken into account. This new variety development was failed to bring coffee production increase or at least maintain its level. Annual production for example was declined from 140 to less than 50 metric tonnes between 1988 and 2011 and production per hectare has reduced from 735 to less than 253 kilograms. In the 1980s a portion of a farmland (26%) in average was not used for cultivation. coffee share was shrinked from 65% of the total farm size in 1980s to less than 40% of the total farm size owned by households (Table 15).

Table 15: characteristics of the coffee and dairy farming at different periods in Murang'a County

Description	1980	1990	2004	2010	2015
Average farm size in acres	4.92	4.60	3.01	2.75	2.60
percentage of land farmed	76.00	91.08	96.00	100.00	100.00
Average ha of land under coffee	3.20	3.60	2.05	1.43	1.03
Average coffee yield in kgs/hectare	735.00	596.00	492.00	264.00	253.00
Percentage of farmers planted new coffee, replace dried coffee	34.61	23.20	3.06	9.05	11.70
Percentage of farmers uproot coffee	-	-	36.30	50.01	49.05
Percentage of farmers left coffee unmanaged	-	-	39.65	34.00	26.47
Percent of land allocated to pasture	24.00	9.02	34.64	54.50	54.67
Average annual milk production in HL	-	5,506.00	9,206.50	36,689.50	50,689.50

Source: household survey data, 2015

Institutional innovation in the coffee sector of Central Kenya

We classified the actors in the coffee sector in to three main categories. The first category includes the national and county government organizations who are the direct contributor and controllers of the sector. The coffee union, the sole and monopoly organization in the coffee development was the strong institution in financial, administrative, technical services until the coffee liberalization in 1992. It was mandated to supply inputs, control the application of rules and regulations on coffee production and supply, while the Coffee Board of Kenya (CBK) was the regulatory body mainly marketing rules. The coffee union contained coffee cooperatives and coffee societies under its structure and farmers supply their cherries to coffee factories, which are the lowest management unit in the supply chain. Quality control and standards are at society level, which is collective, implies low quality coffee supplied farmers also shares the revenue of coffee of good quality supplied by other farmers due to quality and standards are collectively done at the milling station after milling is commissioned (Figure 19). Particular to the period after liberalization, smallholder coffee production was left weak where input prices were higher and accessed through private dealers. The power of the coffee union transferred to the newly emerged and many in number primary cooperatives commonly called coffee societies. Coffee primary processing factories were owned by the coffee societies to process the cherries and supply to private millers (Figure 19).

The second category of actors is the research and education institutions. Kenya Agricultural and Livestock Research Organization (KALRO), is the sole national research organization organized in 16 research institutes. Coffee Research Institute (CRI) is the institute responsible for researches on coffee (breeding, agronomic, socio-economic and bio-chemistry). International research institutions for example members of CGIAR (ICRAF, CIAT,), ICIPE, CIRAD, or joint research programs and projects with AU, EU, DANIDA etc. are among the organizations who have research projects in the coffee particularly agronomic and pest management.

The third category was the development and community based organizations such as USAID, DANIDA, AgroproFocus, SIDA, and others.

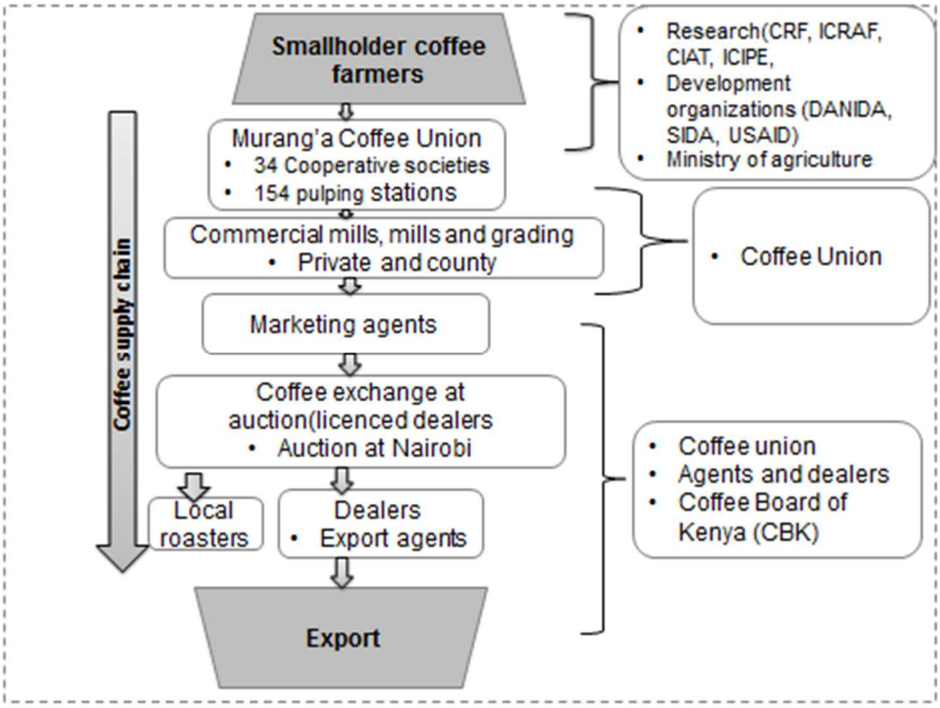


Figure 19: Smallholder coffee supply chain and actors interaction in Kenya

5.4.2. Innovation in the dairy sector: An example from the dairy sector in Central Kenya

Technological innovation

The dairy sector development initiative was mainly on three broad categories of functions. These are (1) Technological development (2) extension and education on best practices of keeping dairy animals (feeding, hygiene, value addition) and (3) institutional building for marketing channels (Table 15). The technological development consist the improvement in breeding qualities and animal health, and access to alternative affordable feed. The extension and education is through the business oriented private sector (veterinarians, feed dealers, health experts). The breeding materials, health services and innovative new feed systems are primarily developed at the research or directly adapted from abroad.

Originally, local cow breeds in Murang'a were the Zebu, which was average for their meet and milk. As farmers' objective was mainly to improve milk production, continuous crossing of the traditional breeds were done, which the breeds finally upgraded to crossbreeds and fully graded cows. Artificial Insemination (AI) of improved breeds was used for improving the breeds. In connection to the breeding technology, farmers experienced the requirement of the new breeds' in terms of feeding and housing. The other technological innovation in the dairy sector was technologies for safety and quality. One of the technologies introduced to boost the dairy sector was installation of 35 dairy cooling plants (each with 5 000 liters capacity) in the milk shed localities. Quality control towards adultery and water content in milk was also introduced at individual level in order to identify the individual suppliers of quality milk.

Institutional Innovation in the dairy sector

Kenya Cooperatives Creamers (KCC), equivalent to coffee union was established in 1925 to support the production, marketing and processing as a sole, autonomous and monopoly agent. The Kenya Dairy Board (KBD), equivalent to CBK was created to regulate the dairy sector. During the first period, cattle breeding was fairly organized and subsidized by the government. Breeding material such as Artificial insemination (AI) was effectively used to upgrade breeds. KCC continued as sole agent for marketing and processing with due protection by policy. The strength of cooperatives and KCC was weak during the second period due to liberalization. Farmers' supply of milk to KCC and other cooperatives was ceased due to irregular payments and delays in response to the liquidation of the agency.

Due to liberalization of the sector all the services previously delivered from the government were stopped. Public breeding and veterinary services was cut back and AI services became inadequate. Private sectors were insufficient and less capable for the service. Feed sector was transferred to private but insufficiently capable. Local feed sources, such as grass, which were the only feed source impacted from climate change. Around the mid of this period, self-help groups and informal agreements started to be emerged. Deregulation of prices for milk created opportunity for different actors to participate in milk marketing and three options for marketing of dairy products notably KCC as government agent, private companies such as Brookside Dairy Limited, Githunguri Dairy limited and the informal channel were created (Figure 20).

The third period was the period of new impetus gave corrections to previous administrative and technical failure. Alternative feed sources such as drought resistance grasses were developed. New commercial feed companies emerged. During this period, the motivation has risen through process due to the milk prices risen and settled regularity, availability of feed at homestead and commercial. KCC was privatized and County cooperatives emerged in a new way. The county government came up with new plans to revive the sector providing and subsidizing the AI, veterinary services, organizing cooperative societies and provision of milk coolers (35).

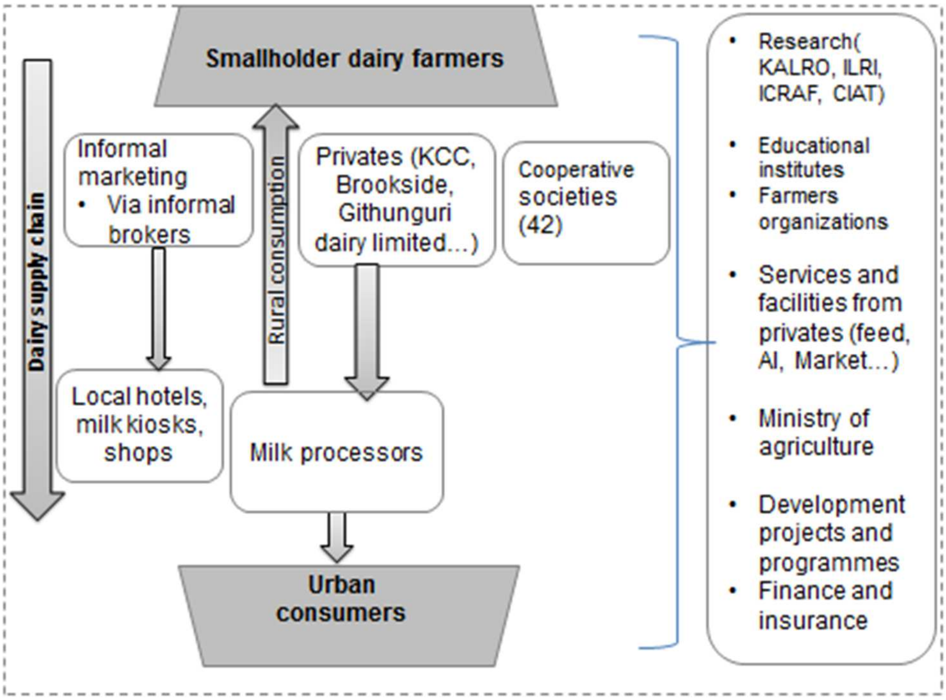


Figure 20: Supply chain of milk and actors interaction in Murang'a County, Kenya

This created a stiff competition between cooperative societies (42 primary dairy cooperatives), private sectors and the newly structured KCC. Fixed price negotiations and contracts emerged. This assured market and assured price motivated farmers to invest in dairy. This encouraged financial and insurance companies also to provide services to smallholders. Feed companies started to emerge. Commercial dairy feeds such as dairy meals, dairy cube, Maize bran, wheat bran, molasses, and cotton seed cake were commonly available at village shops. Annual milk production and per capita consumption, therefore, shot up.

As a second level contributor to the dairy sector, national and international research institutions are among the basic actors in the sector. National research organization particularly Kenya dairy research institute and Kenya beef research institute are the national research institutes responsible for the dairy development of the area. International research organizations such as members of CGIAR (ICRAF, ILRI, CIAT, CYMIYT,), ICIPE, or joint research programs with AU, EU, e.t.c. are among the responsible organizations in research. Demonstration and trail sites of higher education institutions such as University of Nairobi, Kenyatta University, and Egerton University were among important actors in research. Third development and community based organizations such as USAID, DANIDA, Technoserve, SIDA, and others. Joint development projects such as Heifers international, East African Dairy development Project. Other development works under the national government such as National, County and sub-county Ministry of agriculture, Ministry of livestock, Ministry of forest resources were among others. The contribution of these instructions towards climate adaptation in the dairy sector was through developing drought resistant feed and feed sources, climate smart housing and breeding mechanisms.

Fourth, private sectors such as Brookside, KCC, Guthunguri, which facilitate marketing and inputs for dairy such as medications, feed and AI, milk cooling machines, milk quality testing and preventing materials were active at the dairy sector.

Fifth, Finance institutions both public and government such as banks, microfinance institutions were key stakeholders in the dairy. Banks such as Equity and Cooperative were among the private banks, which provide credit to dairy farmers. Government finance such as Agricultural Finance Cooperation (AFC) and Kenya Commercial Bank (KCB) also provide financial services.

Collaborative projects and programs with effective and efficient coordination were common in the dairy sector. The EADD program is for example implemented by a consortium of Heifers international, ILRI, Dairy cooperatives, Technoserve, African breeders services total cattle management limited and ICRAF focusing on improving breeding and animal health, improving feed management, and improving market access particularly smallholders. Such types of coordinated action bring different options for farmers for input supply, financial support and marketing access. Organized system of access to feed was arranged and linked with private feed companies and trainings on processing and management of feed was given by dairy training institutes. Market arrangements and contract agreements were done with the county government, private milk processing companies and dealers. Access to insurance for cows was also one of the agreements included in the package.

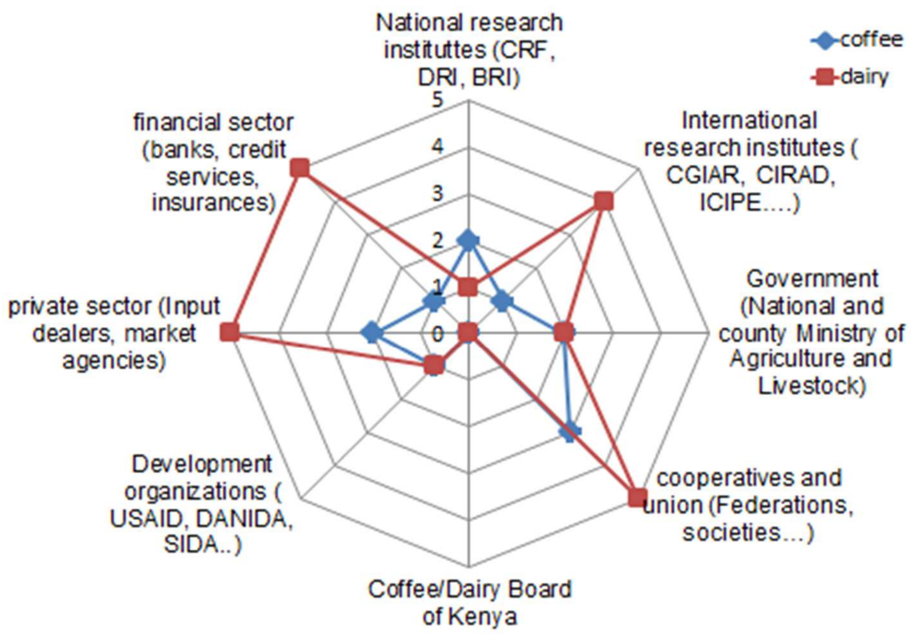
5.4.3. Comparison of the contributions of actors in the coffee and dairy sectors

The results disclosed actors differ in their contribution to the development of coffee and dairy sectors. Coffee farmers are less supported in material and input compare to dairy farmers. Among the actors in coffee, the cooperative society, the county and national government are the organizations participated in provision of material supply such as input though it is not sufficiently provided (Figure 21a). In the dairy sector on the other hand, the cooperatives, financial sectors (banks, credit and insurance companies), private sectors (input dealers, market agencies), and international research institutes (CGIAR, ICIPE…) are the primary actors contributing towards input and material supply (Figure 21a). Access to financial and credit services also differ on the farming system the farmers depend on. In the coffee sector, though it is not satisfactory, the cooperatives and the private sectors are the main actors providing financial and credit service to farmers (Figure 21b) while dairy farmers are satisfactorily served by the financial and credit institutions such as government (the county and national ministry of agriculture and livestock), cooperatives and farmers federations, private sectors (input dealers, market agencies) and financial sectors (banks, credit institutions and insurance companies) (Figure 21b).

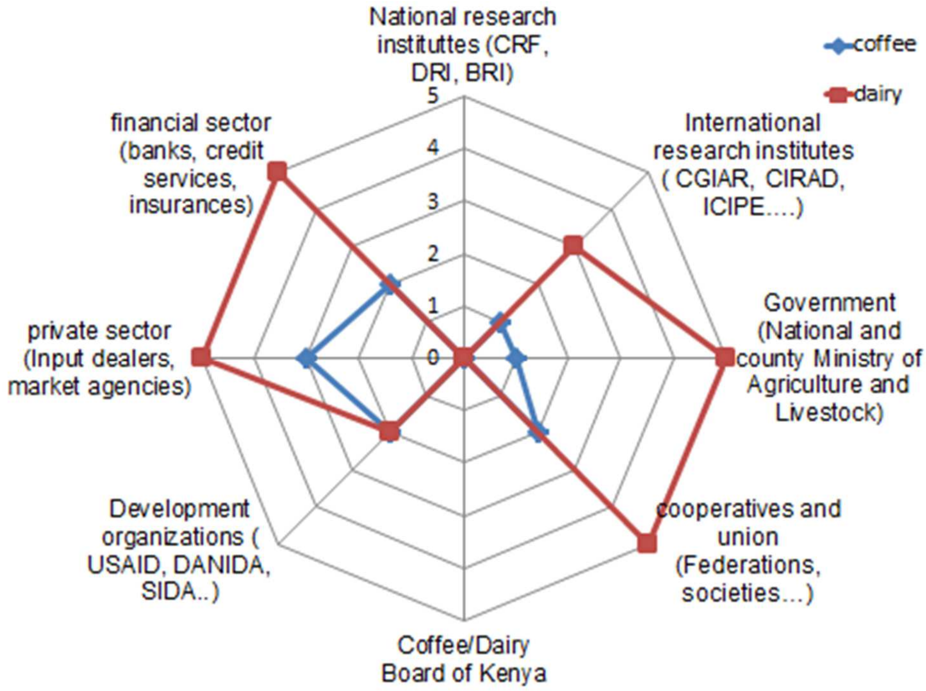
Regarding to market access and facilitation, the cooperative union is the sole and autonomous organization to process and market coffee although private marketing agents are the powerful actors (Figure 21c, Figure 19). The marketing at the auction was done through an agent hired by the cooperative union for its export (Figure 19). Prices were controlled by the top chain actors and farmers were price takers, where every transaction and payment is not in less than six month. The system is an opportunistic coordination where the actors at the auction and union are the lead firms with information asymmetry with the farmers and societies where producers and the marketing bodies are disconnected and farmers hardly know the quality requirements. Farmers insufficiently know the market price of their coffee and the share of every actor in the system. Results from the dairy sector explored cooperative unions and federations, private market agents (KCC, Brookside and Guthunguri dairy limited, individual brokers), development organizations (USAID, Technoserve, SIDA..) and international research institutes through their collaborative projects and programs are the primary actors in organizing farmers, facilitating and arranging access to market (Figure 21c, Figure 20). These actors are equally distributed throughout the value chain. In the dairy sector open competition of dealers, farmers' decision in price making and transparency are bolded. All the dairy buyers organize and register farmers for better power in production, input service, and marketing.

The results on information and knowledge provision disclosed that CRI, cooperatives and farmers federations are the primary sources of information and knowledge for coffee farmers while there is also limited contribution from international research institutes (CGIAR, ICIPE…), County and national government of Ministry of agriculture and livestock, and other development organizations (Figure 21d). In the dairy sector, actors such as cooperative unions and farmers federations, national and county government ministry of agriculture and livestock, international research institutes (CGIAR, ICIPE..), financial sectors (banks, credit institutions and insurance companies), private sectors (input dealers and market agents) and development organizations are the primary providers of knowledge and information (Figure 21d).

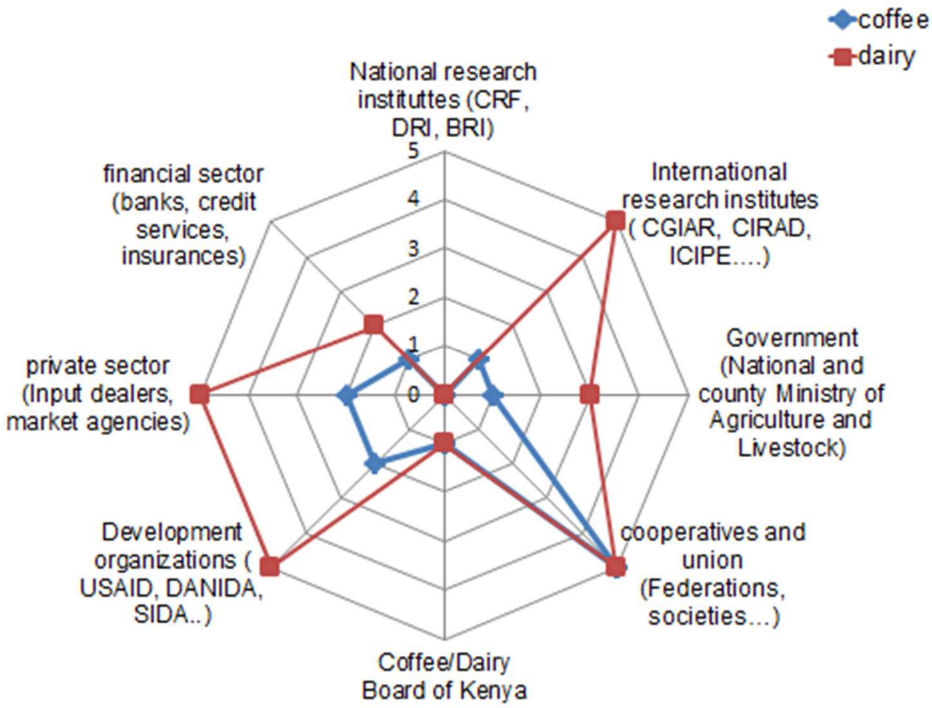
a. Contribution input/ material supply



b. Financing and credit service



c. Market access and facility arrangement



d. Knowledge/ information provision

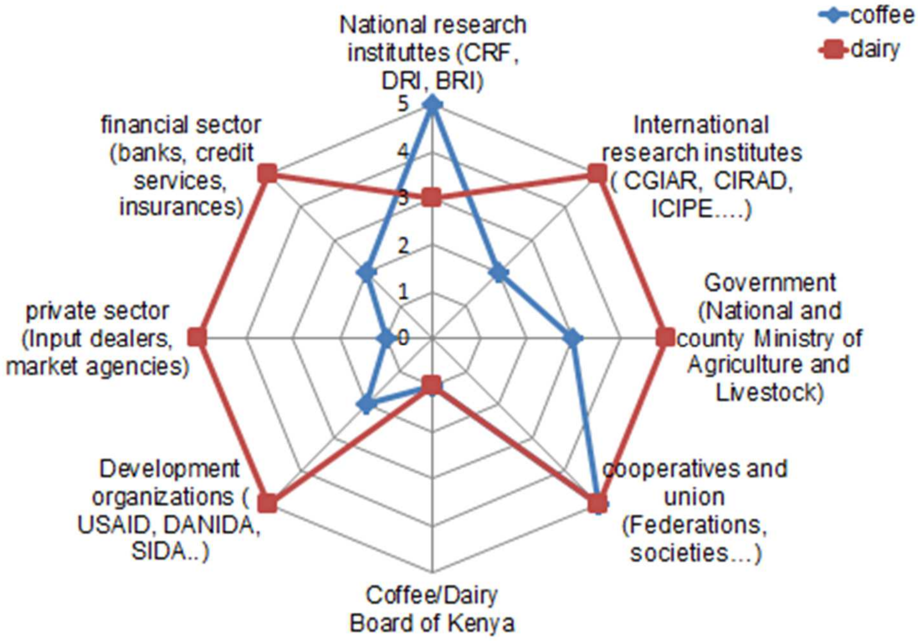


Figure 21: Actors contribution towards the development of the coffee and dairy sectors
Note: 5= very high, 4=high, 3=medium, 2= low, 1=very low, and 0=no contribution at all

5.5. Discussion

Macro level agreements, such as the Paris agreement of the UNFCCC should have to bring to discussion how to tackle climate change using institutional innovation through better marketing and other enabling environments for technological innovation. Technological innovation is indeed important, but it is not the only requirement. Enabling environment where the technological innovations could work would be the priority area. In the coffee and dairy sector in Central Kenya, before market liberalization, there was an organized input delivery and marketing system in the coffee and milk collection and bulking system in the dairy sector (FAO, 2011) through a coordinated and monopoly cooperative agents. The two sectors experienced decline during the early years of liberalization, but later on took different directional trends. While the coffee sector has continued to decline and enter in full recession, the dairy sector flourished. The main idea of this discussion is, therefore, to understand why these two systems took a different trajectory and what these shifts in farming system brings to household adaptation strategy and food security.

The cooperative system and monopoly service of the coffee and dairy collapsed similarly and their economic performance declined. Both sectors were stayed in a recession and poor performance for a decade. After a decade of recession, however, the dairy sector begun to revive and become an emerging economic frontier, while the declining in the coffee sector continues. Three main reasons contributed the two sectors, which were in the same case to take a different direction growth. First, the coffee development program was continued on technological development such as diseases resistance new varieties, which is supply push top down innovation whereas the dairy sector development was a demand driven. Second, the two systems followed different value chain policy where in the coffee sector input and other services were left for the private with less attention, while the marketing section was cooperative based monopoly supply system. The dairy sector on the other hand, was fairly liberalized and the cooperative, private sectors and informal dealers equally compete for the service delivery. For the coffee sector there is a long line vertical supply chain, while the vertical supply chain of the dairy sector is short, rather dominantly the actors are equally participated at the grassroots level. Third, the two sectors also differ in actors and their interactions: in the coffee system, actors are relatively few and focus on supporting the production technologies. In the dairy systems, actors and many and fairly well distributed throughout the supply chain. They equally participate in the production, collection, marketing and distribution.

The capacity to innovate to adapt to changing climate in the coffee agroforestry systems is dependent on the roles of enabling institutional environment, such as market, supply chain system than the need to bring a new technological system, such as new varieties, biotechnology and breeds. These breeds and varieties are chosen for their adaptability to climate change and economic importance. In the case of the coffee sector, diseases resistant new varieties development is indeed important but the innovation towards better agronomic practice and innovation at the marketing and other enabling environment of the technological innovation such as the means to outreach the varieties, the required packages for it and the marketing system of coffee are equally important. On the dairy sector, the works were more of institutional development, such as creating market for dairy through building active and powerful cooperatives, the innovation on how the technological innovation could work for example, the milk cooling machines and milk collection and cooling system, access to feed through organized cooperatives, access to breeding materials, which is through the active involvement and participation of private business. These are the reasons for the dairy sector resiliency to climate change. A study from the dairy sector in Kenya explored that farmers' innovation needs the development of new technologies and information, better support services for input access and infrastructural facilities for delivering their products to markets (Schreiber, 2002). Cooperative institutions are for instance potential catalyst for cost of production and marketing minimization, stimulate entry to market and promote growth of dairy firms. The performance and efficiency of the sectors, however, depends on the roles and performance of the actors, their interaction and co-production of knowledge (Klerkx & Nettle, 2013)

Economic and climate pressures are already major issues in most of sub-Saharan Africa and policy actors have to look for micro studies on how systems of innovation in farming systems could help for adaptation to climate change. Here, impacts are also different to different systems where systems differ in sensitivity and exposure to changes. Consideration of the systems and actors capacity to adapt could bring impressive results. In the traditional business as usual model, integrated farms that owns both crops and livestock is more resilient to climate change than specialized farms (Seo, 2010). But the specialized farms could be more important in terms of profitability particularly in the cash based systems. In the new model of innovation system perspective, innovative system design which incorporate technological and institutional innovations could be the corrective measures of the problems of specialized farming. A good example is the coffee and dairy sector in Central Kenya. In connection to this, we suggest two policy implications in relation to this study, i., e within the sector, and across sectors. Within the sector, the dairy in Central Kenya, which have organized input supply and marketing system coordinated by different actors could be an example for other areas. Innovation in the dairy sector helps dairy farmers to be resilient of climate change through enhanced income and sustainable production. Across sectors, it may give emphasis to the coffee sector to have a collaborated and coordinated public and private sectors to work together and invest in climate change adaptation strategies. The dairy sector in Kenya could be an exemplary for the development of the coffee sector. Due to changes in climate farmers are changing their coffee farms but this shift can be triggered by the institutional and technological innovations.

CHAPTER SIX
SYNTHESIS OF RESULTS, DISCUSSION AND GENERAL CONCLUSION

6. RESULTS, DISCUSSIONS AND CONCLUSIONS: A SYNTHESIS

6.1. Introduction

This Thesis has been studied the adaptations to climate change in the coffee agroforestry systems of Central Kenya. In this Thesis, we have shown that effective adaptation to climate change considers: - (1) the knowledge on climate change and climate change adaptation, the motivation towards adaptation and the behavioral and attitudinal change towards adaptation, (2) the technical practice, availability of adaptation options, capacity and asset ownership to adapt, and the cause-effect relationship between adaptation practices and household income, and (3) the roles of system of innovation and institutional context to bring new frontier of adaptation to climate change considering the sectoral differences and capacities to adapt to the changing climate.

The first Chapter of the study introduces the Thesis, the overall context of the study, states the problem, and presents the theoretical and conceptual framework of the study. This emphasizes on presenting the situation and stating the problem before proceeding to the independent but consecutive chapters, which are derived from the general objective. Chapter 2, presents the general methodological approach, which includes description of the study area in general, and the data and methods used in this study. This study was conducted in two agro-ecological zones and four farming systems. The agro-ecological zones are specified as coffee zone and food crop zone. Coffee zone is an area dominantly used for coffee production, which is stretched from mid to high altitude, while food crop zone is dominantly at the lower altitude. Regarding farming systems typologies, the lower altitude is dominantly q food crops area, while dairy production is common to all zones. Food crop dominant farmers earn their farm revenue from food crops. The second typology of the farming system is the coffee system, where farmers dominantly depend on coffee, and coffee production is their specialized practice. Third, coffee-dairy diversified system is a farm typology, where farmers depend on the revenues of coffee and dairy almost equally. Fourth typology is specialized dairy system, where farmers commonly depended on dairy production, and dairy is practiced as a commercial production.

The Chapters 3-5, includes the detailed consecutive and interlinked studies. Regarding to climate change knowledge as a precondition for farmers' adaptation to climate change, Chapter 3, discusses, how the integrated evidence of climate change, which coined two sources, i.e., the farmers' perceptions of climate change, and historical climate data supports climate change adaptation policy, and the need to integrate the two knowledge sources. Using the evidences differently may be a reason for different interpretations to a common problem of climate change. The use of the local people's knowledge, and scientific methodology supplements each other to better understand and interpret the problem.

Adaptation as a policy priority may be rhetorically non-controversial, but what this means to different actors, such as farmers, and other scientific communities depend on particular source of information, and interpretation. The understanding of changes from farmers' perspective and stochastic analysis of historical climate data so far are studied separately, and researches that consider both sources in order to understand the compatibility and/or discrepancy are insufficient. It has so far predominantly been researched either from farmers' side or scientists' side, and the farmers' knowledge is yet to be taken in to account for policy decisions though farmers are the primary actors expected to implement adaptation actions in agriculture. Therefore, this chapter was aimed at: (1) characterizing the changes in climate of the study area as perceived by farmers; (2) identifying climate change patterns from local historical climate records; and (3) comparing the farmers' perception with the historical meteorological climate data to assess consistency/ discrepancy among these, and potential for integration of what to support to adaptation policy.

Understanding the knowledge level of farmers on climate change is, however, insufficient in the process of development of concrete measures towards adaptation, unless adaptation choices and practices, their importance is taken in to account. The difficulty to understand, and consider farmers' choices holds back the progress towards adaptation even in places with proven impacts of climate change. In this case, farmers may be fully aware of the changes in climate and challenges, which are already happening. Chapter 4, therefore, evaluates farmers' responses to current environmental and societal changes, their perception of climate change, and variability in order to define adaptation strategies to climate change. In this chapter, whether farmers, who do perceive climate change, and do not perceive the climate change implements similar strategies is included. In connection to this, what determines the farmers' adoption of climate change adaptation choices, and the implications of the adoption to household income is emphasized in this chapter. This chapter also emphasizes, whether adoption of multiple adaptation strategies brings higher benefits, or implications than adoption of the strategies in isolation.

More importantly, the understanding of climate change knowledge, and implementation of farmers' micro farm level adaptation strategies was preceded with the part that deals on the roles of systems of innovation and institutions in driving options to adapt to climate change. This claims, sectoral innovation performance to adapt to climate change depends on the performance of institutions and actors interaction. This is in response to the difference from sector to sector in actors and their nature of interaction. Chapter 5, therefore, explores and presents the structural and institutional approach to system of innovation to adapt to climate change particularly in the coffee and dairy sectors as a case study. This included the institutional characteristics of systems of innovation particular to each sector. This basically provides an answer to the questions such as: - what characteristics of the systems of innovation are particular to each sector in the adaptation process? And how these characteristics of the innovation affect the adaptation process and competitiveness of the sectors?

The remaining part of this chapter first presents the main findings of the Thesis. This is followed by a discussion of major contents and results. Then, contributions of the research towards the theory, empirical literature, methodological approach, development and policy implications are present. These are followed by further implications and general conclusions. Finally, the chapter provides suggestions for further research and concludes with some major statements.

6.2. Main findings

Farmers' knowledge of climate change is a result of their life long practical experience, through observation of the changes in temperature, rainfall, and the environment in general. Changes in seasons, weather patterns, and changes in character of indicators of change are among the top explanations of farmers. Three indicators, notably, trends observed in patterns of rainfall, trends in temperature, and observation of the effects of the changes are the indicators for farmers' to perceive changes in climate. Particularly, results showed that delayed and incomplete onset of rainfall, short durations and decreased frequency and intensity of rainfall are among the indicators for farmers' perceptions of rainfall. Farmers perceived several changes with respect to temperature patterns: a prolonged dry season that included dry spells, a change in temperature patterns; extreme sunny dry seasons and extreme but unpredictable cold rainy seasons, which makes them to be less confident of when it will be cold and when it will be hot (Chapter 3).

Trend analysis of long-term historical climate data indicated the climate was indeed changing. This found spatial differences comparing different agro-ecologies and temporal differences comparing different timelines. Mean minimum and maximum temperature was found in an increasing trend throughout the last three decades for both the coffee and food crop zones. Mean annual rainfall was, however, higher in the coffee zone compare to the lower altitude food crop zone. In the coffee zone, rainfall was found to decrease continuously, while no clear trend was found in the food crop zone unlike seasonal and annual variabilities. This was proved by the results from Mann-Kendall trend analysis and Sen's slop estimator. Considering mid-March as the "standard" onset and "mid-June" as standard offset of rainfall of the past, current results indicated a delay in onset and early offset of rainfall. Regarding specific periods, our analysis indicated three different periods. Prior to 1991, onset was entirely early, while the periods between 1992-2001, and since 2002 onset were very variable and entirely late, respectively (Chapter 3).

The comparison between farmers' perception and historical trend analysis of climate change to understand the consistency versus discrepancy show that the farmers' perceptions of temperature change were consistent with the historical trend analysis for both food crop and coffee zones, while discrepancies were found for rainfall in the food crop zone, for which there was no evidence in rainfall records to support farmers' perceptions of decreasing rainfall over time. Farmers' perceptions, and historical trend analysis were consistent, however, about the rainfall patterns (i.e., onset, duration, cessation, and variability).This consistency (discrepancy) determines the adaptation policy. Farmers prefer to bring changes in the agronomic practices, and diversify their income sources accordingly, while policy actors prefer macro level long term investment strategies, such as institutional building. An integrated interpretation taking into account both knowledge sources to identify adaptation needs could better support locally-adapted policy aimed at adapting to climate change. These adaptation policies have to take into account the spatial disparities, and temporal differences.

The long-term rise in temperature evidenced by various studies (Armah *et al,* 2015; Dhanya and Ramachandran, 2015; Kemausour *et al.,* 2011), confirms, the consistency of information obtained from both the historical climate data and local farmers' perception in both the coffee and food crop zones. A study by the World Bank (Maddison, 2007), in a broad scope of African countries indicated farmers perceived the climate has become hotter, and that long-term climate data from meteorological stations substantiated farmers' perception. Findings from South Africa (Bryan *et al*. 2009), indicated that farmers' perception, and recorded data both agreed about the occurrence of a significant increase in temperature. Others, such as Silvestri *et al.* (2012); Eriksen & Lind (2009); Adimassu *et al.* (2014), also consistently contended temperature has increased showing mutual results from the historical record and farmers' perception. Similar results have been found about the farmers' perception and historical data of rainfall in other coffee growing areas. Mwalusepo *et al,* (2015), found agreements between farmers perceptions and historical data for Mount Kilimanjaro of Tanzania and Taita hills of Kenya.

Discrepancies are, however, observed between farmers' perception and historical data of rainfall at the food crop zone: the analysis of annual records of historical data of rainfall provided no evidence to support farmers' perception of declining trends, other than agreeing about interannual variability and pattern differences. For their part, Mwalusepo *et al,* (2015) found inconsistency of farmers' perception and historical data for Machakos farmers in Kenya, while consistent results were found for Mount Kilimanjaro of Tanzania and Taita hills of Kenya. Similarly, Zampaligr *et al*, (2014) in western Africa and Simelton *et al*. (2013) in Southern Africa, reported a discrepancy between farmers' perception and historical data of rainfall. A comparative study of farmers perception and meteorological data of rainfall by Bryan *et al* (2009) showed that there was no clear statistically significant trend of declining rainfall in South Africa over the 1960–2003 periods, while farmers for their part perceived a steadily decline.

Current choices of adaptation strategies to climate change (Chapter 4), defines different options implement by different category of farmers. The choices are categorized as, crop management choices, livestock management choices, and livelihood options. The results showed coffee, and food crop farmers have different choices to adapt to climate change. Food crop farmers were found using short maturity crops, adjusting planting and harvesting dates in relation to onset, and offset of rainfall, while coffee farmers are found to change varieties depending on duration of rainfall, and shifting crops depending on rainfall predictions.

Coffee and food crop farmers are found to respond to the changing climate differently. However, literature that comparing choices between coffee and food crop farmers is insufficient. Studies from Central America and Mexico (Tucker *et al*., 2010) claims different adaptation choices for coffee farmers, and other studies, such as Bryan *et al.,* (2013), Nhemachena & Rashid (2008), Lin (2011), describe adaptation choices to climate change pertinent to food crop farmers. Though these discrete studies were conducted separately, at different locations, we found that researches done on coffee and food crop showed similar results. Changing crops varieties, choice of crop types, improved farm inputs management, diseases control, crop-livestock diversification, and controlling of stocking rate of livestock were mostly used by coffee farmers, while adaptation choices, such as tree planting, irrigation supplementation, intercropping, adjusting planting and harvesting dates in response to rainfall onset and offset, and permanent or temporary migration were mostly adopted by food crop farmers.

Primarily, the study compared the adaptation choices of coffee and food crop farmers. The second hypothesis needed to test was if farmers who perceive and do not perceive climate change equally adopts adaptation choices. This proves, if the choices are for responding to the changing climate or other determinants, such as economic pressure. Thus, therefore, found a significant difference among coffee farmers who perceived climate change and do not perceived climate change in adoption of choices, while no significant difference is found between food crop farmers who perceived climate change and do not perceived climate change in adopting choices except for variety change. The results explored that farmers who perceived the climate has changed adopted more choices compared to farmers who do not perceived changes. However, this is not an exclusive conclusion adaptation choices could be for different reasons, i.e. perceived the climate has indeed changed and a response to the changes and non-climatic drivers, such as economic pressure or expected benefit.

Investigating further, on why farmers decide to adopt adaptation strategies and how they choose one over other strategies depends on different factors. Decisions on adaptation choices considers two purposes i.e., expected profit from adoption of the choices and avoiding some kind of risk, which could be caused in its absence. Adopters of any adaptation strategy in this study were found to be better off compared to the non-adopters, showing higher income in all cases. The comparison between the adoptions of single choice also revealed that irrigation adoption yields higher income followed by varietal change and mixed crop-livestock diversification, respectively. The comparison also revealed that although the choices in combination and separately have significant and positive effect on household income, adoption of combination of packages benefits farmers more than single strategy.

Our results on the likelihood of choice of adaptation strategies, which are influenced by explanatory variables confirm results from previous studies. Family size was found to determine adoption choices such as irrigation, which is similar to results from (Abid *et al*., 2015; Deressa *et al.*, 2009), while education of the household head was found to have positively correlated with a combined crop-livestock diversification, variety change and irrigation (MIXVARIRR). Household farm income was found to determine all the choices of adaptation positively. Similar studies such, as Deressa *et al.,* (2009) finds farm income positively affect choice of irrigation and variety, while Teklewold *et al* (2013) explores a positive significance relation between annual farm income with cropping diversification and variety change.

Access to credit was associated to Crop-livestock diversification (MIX), variety change (VAR) and combined crop-livestock diversification and variety change (MIXVAR), where similar studies such as Tekelewold *et al* (2013), Gebrehiwot & Van Der Veen (2013) find a similar result. The analysis of the adaptation choices in this study considered both the farmers who perceived climate change and farmers who did not perceived climate change unlike previous studies, such as Deressa *et al*., (2011). Significant portion of the farmers who did not perceived a change was found using some adaptation strategies. This could be due to economic, such as income or other drivers and it disprove the conclusion; farmers adopt adaptation choices if and only if they perceive changes. The strong correlation between the socio-institutional variables and choice of adaptation strategies suggests the need for the establishment, and strengthening of local institutions, such as micro-finance and extension institutions. These institutions have the capacity to break the capital constraint of farmers to invest through provision of credit and advisory services.

It was hypothesized in this Thesis that the micro-economic farm level adaptation to climate change is insufficient unless supported by the systems of innovation and institutional dimension. This assumed the strategies to adapt to climate change are dependent on the roles of the systems of innovation and institutions to provide support and create conditions, where farmers could implement adaptation strategies. The third part of the Thesis, therefore, shifts the understanding of climate change adaptation from micro farm and household level strategies to an institutional context. This chapter was, aimed at analysing the roles of systems of innovation to adapt to climate change the case of coffee and dairy sectors in Central Kenya. This specifically analyses: - (1) what characteristics of the systems of innovation are particular to each sector in the adaptation process to climate change? And (2) How these characteristics of the innovation affect the adaptation process and competitiveness of the sectors?

Despite the technological changes and behavioral change towards adaptation, social needs and institutional conditions beyond technological development are important elements in the process of adaptation to climate change. In this regard, the roles of institutions in driving options to adapt to climate change (Chapter 5), claims the sectoral innovation performance depends on the performance of institutions and actors interaction. This was in relation to the premises of adaptation choices to climate change needs support from the institutional context. Subsequently, we identified two sectors that differ in terms of actors involved, enabling environment and institutional and organizational setup, i.e., (1) technological and institutional innovation to specialize on coffee, and (2) innovation towards the development of dairy sector. The results finds that (a) Actors in the coffee are limited, the system is highly centralized with limited options to farmers to process and market their product, while the dairy sector is informally controlled by demand based business, comparatively numerous actors, (b) The innovation in the coffee sector was on the technology development, while the dairy sector was mostly on institutional building.

The cooperative system and monopoly service of both systems collapsed similarly and their economic performance declined. Both sectors were stayed in a recession and poor performance for a decade. After a decade of recession, however, the dairy sector begun to revive and become an emerging economic frontier, while the declining in the coffee sector continues. Three main reasons contributed the two sectors, which were in the same case to take a different direction growth. These are;-

1. The coffee development program was continued on technological development such as diseases resistance new varieties which is supply push top down innovation whereas the dairy sector development was a demand driven.
2. The two systems followed different value chain policy where in the coffee sector input and other services were left for the private with less attention while the marketing section was cooperative based monopoly supply system. The dairy sector on the other hand, was fairly liberalized and the cooperative, private sectors and informal dealers equally compete for the service delivery. For the coffee sector there is a long line vertical supply chain while the vertical

supply chain of the dairy sector is short, rather dominantly the actors are equally participated at the grassroots level.

3. The two sectors also differ in actors and their interaction where actors in the coffee are limited and centered at supporting the production technologies while actors in the dairy are fairly distributed throughout the supply chain. Actors symmetrically participate in the production, collection, marketing and distribution of the dairy sector.

The capacity to innovate to adapt to changing climate in the coffee agroforestry systems is dependent on the roles of enabling institutional environment such as market, supply chain system and… than the need to bring a new technological system such as new varieties, biotechnology and breeds. In the case of the coffee sector, diseases resistant new varieties development is indeed important but the innovation towards better agronomic practice and innovation at the marketing and other enabling environment of the technological innovation such as the means to outreach the varieties, the required packages for it and the marketing system of coffee are equally important. Dyer & Singh (2012) identified knowledge sharing and inter-organizational learning, complementary resource development and capacity, and effective governance are crucial for firms' performance.

The exclusion of farmers and their institutions in technology development particularly coffee management technologies hinders the performance of technological innovation (Cerdán et al. 2012). This implies institutional innovation towards management decisions and practices maintain coffee productivity. On the dairy sector, on contrary, the works were more of institutional development such as creating market for dairy and dairy products through building active and powerful cooperatives, the innovation on how the technological innovation could work for example, the milk cooling machines and milk collection and cooling system, access to feed through organized cooperatives, access to breeding materials which is through the active involvement and participation of private business and sectors. A study from the dairy sector in Kenya explored that farmers' innovation needs the development of new technologies and information, better support services for input access and infrastructural facilities for delivering their products to markets (Schreiber 2002). Cooperative institutions are for instance potential catalyst for cost of production and marketing minimization, stimulate entry to market and promote growth of dairy firms. The performance and efficiency of the sectors, however, depends on the roles and performance of the actors, their interaction and co-production of knowledge (Klerkx & Nettle, 2013)

With these main findings from the different case studies, the results are summarized below and below and put in accordance with the conceptual diagram and the research objectives as presented in the introduction. This summarizes, how household and farmers' income depends on farmers' capacity to adapt to climate and other changes (Figure 22). The farmers' adaptive capacity (collective result of the three studies, study I-III), depends on three dominant elements, or steps of adaptation to climate change (Figure 22). (1) Climate change knowledge, which includes local peoples knowledge in the form of perception, attitude and behavioral change towards climate change and adaptation; (2) understanding adaptation choices, which are farmers' technical implementation of strategies, understanding the determinants for the adoption of the choices, farmers willingness and ability to adapt to choices in order to improve their livelihood; (3) institutional innovation, and enabling environments for farmers to know the changes and adopt adaptation strategies.

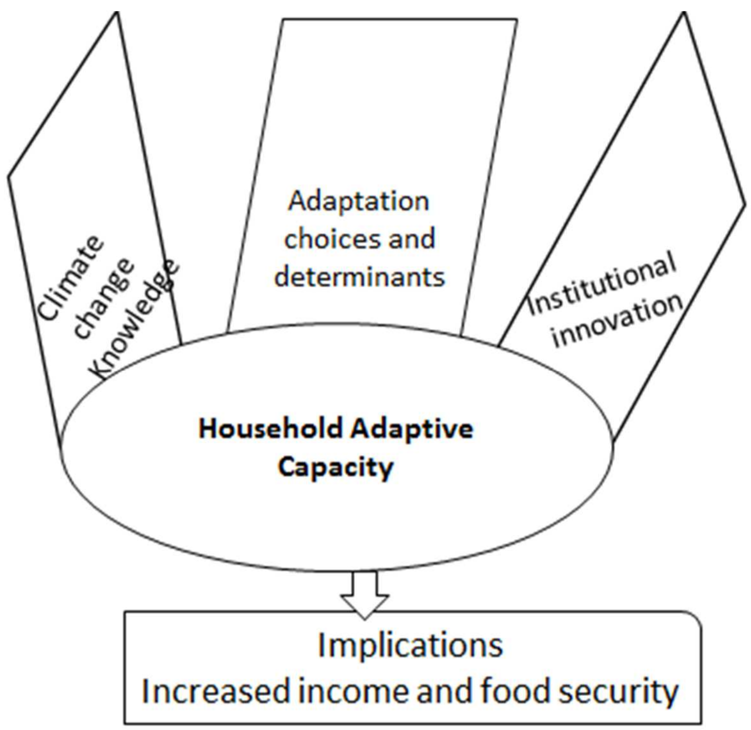


Figure 22 : Summary representation of results

6.3. Theoretical contribution

The Thesis contributes to the newly emerging theory and cognitive of "Innovation economics" that emphasis on approaches in terms of systems of innovation to explain the emergence of new fields that could be in the adjustment of the economy. This potentially refers to adaptation in a system of Innovation, specifying the farming system economics, production economics and systems of innovation approaches from the points of climate change adaptation economics. Climate change adaptation concepts and theories, such as frontiers to adaptation (Downing, 2012; Adger *et al*. 2005), the need for adaptation and mitigation (Lobell *et al*., 2008), cost of adaptation (Fankhauser, 2009), adaptation capacity and vulnerability (Smit and Wandel, 2006), scales of adaptation (Lobell and Field, 2007) are fairly rich in the literature. The attempt to define economics of adaptation and mitigation to climate change has been focused basically on modeling the implication of emission reduction, estimating economics of technological options (Stern, 2006), and statistical crop model (Lobell *et al.,* 2008). The theory of economics of adaptation, such as decision process and options is, however, new concept and unsolidified in the literature.

This Thesis, therefore, contributes to the development and solidification of the newly emerging concept and theory of economics of adaptation. Particularly, it contributes towards theory and concept building on (1) the link between adaptation, farm production and farming system economics; (2) innovation dimensions and economics of adaptation; and (3) the need for institutional infrastructure in the innovation process in order systems able to adapt to climate change. This includes the economics of decisions of implementation of actual adaptation strategies particularly in developing countries, policy options for international assistance for implementation of strategies which are rich in abatement of emissions.

6.3.1. Farm production and farming system economics in the context of climate change adaptation

Farm production economics depends on the types of inputs and outputs and farm typologies (Debertin, 2004; Teece, 1982; Just & Pope, 1978; Charnes *et al,* 1978).

This includes the material inputs, and the behavioral and attitudinal readiness of farmers, which is based on different knowledge and perception systems. This determines the decision to implement different adaptation strategies to climate change. This Thesis advances the body of literature on the conditions farmers choose specialization, and diversification of production. For instance, some category of farmers prefer to continue on specialization of coffee having the conditions of technological innovation to bring diseases resistant new varieties, agronomic practices and input facilities, institutional performance towards supporting the coffee sector and the agro-ecological suitability. With the absence of all or part of the services and facilities, farmers prefer either to diversify to dairy or food crops or completely shift to specialized dairy production, provided that the dairy sector is still encouraging. This depends on the business model and innovations towards the production systems and performance of production systems. This Thesis, therefore, provides to the body of literature the kinds of production typologies and the pertinent adaptation strategies to the specific farm typologies in order to develop a beneficial farm business model.

Similar to the concept of farm production economics, in this Thesis, we explore the adaptations to climate change is farming system specific and depends on farm typologies. Food crop, coffee and livestock farmers adapt to climate change differently. This implies, adaptation choices are farming system specific. Literatures so far; such as the IPCC reports (IPCC, 2001; IPCC, 2007, IPCC, 2014) are rich mainly on global and regional contexts in a general frame. This study could be, therefore, a base for the development of framework, concept and theory building, guideline for policy devise, and practical implementation of strategies, which is location and farming system specific at a local context.

6.3.2. Approaches and dimensions of innovation: towards a new domain of economics of adaptation

Our Thesis contributes to the concept of economics of innovation in adapting to climate change, and how it helps smallholder farmers achieving food security. Researches on systems of innovation mainly on the approaches, and dimensions of innovation (Edquist & Hommen 1999; Rolling, 2009), the shift from measuring an empirical impact to learning the institutional innovation (Hall *et al*, 2001; Hounkonnou *et al*. 2012; Klerkx & Leeuwis 2009; Rajalahti *et al*. 2008), the roles of innovation in co-evolution (Kilelu *et al*, 2013), innovation and actors interaction (Klerkx *et al*. 2010), and sectoral innovation and production systems (Malerba, 2002), commonly advances in the literature.

This Thesis connects the dimensions of system of innovation, which mainly emphasis on technological, institutional, and sectoral systems of innovation, and its relationships with the adaptation strategies to climate change, and the roles of institutions for both the innovation performance, and adaptation process. This also shows the relational pathways of institutional innovation, adaptation to climate change, and what it brings to household food security, and livelihood development particularly in the coffee agroforestry of developing countries. Furthermore, this Thesis opens-up to a new way in the agricultural research development giving a way to national and international research system mainly on, why the research and system of innovation of some sectors is efficient, while not yet in other systems. It also contributes to literature the innovation and adaptation steps that include the knowledge system, the current actual practices and investments on climate smart, and the institutional innovation and reformation towards adaptation to climate change to bring better household food security.

6.3.3. Institutional infrastructure: need towards adaptation process

Perceptions towards climate change and adaptation to climate change are indeed important steps in the adaptation process. The micro-economic farm level innovation to adapt to climate change through application of different household strategies depends on the knowledge level of the problem and the expected benefit of the technologies. Technological innovations are indeed important in the adaptation process. This, however, requires different infrastructural facilities. In this regard, adaptation requires an institutional innovation. The strategies of adaptation to climate change are, therefore, dependent on the roles of institutions to provide support and create conditions, where farmers could implement adaptation practices to climate change. This raises the question of relevant networks for Innovation (Grin, 2010;

Vescovi *et al*., 2009), the issue of density, the nature and process of building links between stakeholders in adaptation process (Boyer, 2016), and the ability of researchers and other actors to capture the empirical traditional knowledge, and tacit, and incorporate them to the coordination mechanism.

This Thesis presents the importance of institutional infrastructure dedicated to enabling environments, such as market, and its contribution in the production process. It requires the involvement of R & D organizations and other actors in the production of knowledge, promotion and dissemination of information. This includes the contribution of the different actors in material supply and technology development, supporting farmers towards accessing and facilitating financial and insurances services, market coordination, which supports farmers to advance their capacity towards adaptation to climate change. In this research, we demonstrated the key role of institutions and organizations, the contribution of market in farmers' choice of enterprises, which finally leads them to transform from a sector, which is financially, and technologically less resilient to a more stable sector or system. Particularly, an assured production, and market, which considers the support of different actors determines the farmers' choice and transformation of sectors; this capacity brings better household food security and dietary diversity.

6.4. Methodological Implication

This Thesis has emphasised on the advantage of using mixed qualitative and quantitative approaches in order to understand the contemporary and complex phenomenon of adaptation to climate change. The use of different sources of information to understand changes in climate, particularly the local people's knowledge, and the scientific perspective, which uses different methodologies advances the analysis of climate change knowledge from different actors. Different types of approaches have been used, to the different chapters and parts with different purposes.

6.4.1. Analysis of climate change knowledge: triangulation of information and methods

The study on climate change knowledge as a precondition for climate change adaptation (Chapter 3) was to test, if farmers' perceptions' are consistent with stochastic analysis of climate data. This is one step forward in the analysis of climate change knowledge, which previously considered either farmers knowledge or scientific analysis of recorded data. Second, the analysis of climate change knowledge was followed by inventory of adaptation strategies implemented by coffee and food crop farmers, determinants of the adaptations, and implications of these choices on household income (Chapter 4). So far, analysis of adaptation to climate change and its determinants (Deressa 2008; Maddison 2006; Shameem *et al.* 2015; Tambo & Abdoulaye 2013), used two levels of analysis. At first level, they analyze farmers' perception of climate change, and at the second level, the adaptation strategies implemented by farmers. These studies, only consider farmers, who perceived the climate is changing, when they analyze the adaptation strategies, and their determinants. This Thesis, however, looked at a different methodology; at the level of analysis of adoption of adaptation strategies, and the determinant factors influencing the adoption choices considered both category farmers who perceive the climate is changing and farmers who do not perceive the changes. This approach helps to understand if adaptation strategies are adopted for the pre-determined perception, and risk or other determining factors. Third, this research methodologically, considered an analysis of two zones, which have different systems, and characteristics. This could be an initial consideration for researches to develop sector, and agro-ecology specific methodologies to understand adaptation to climate change.

6.4.2. Sectoral analysis of adaptation to climate change

For all agricultural systems, appropriate adaptation to climate change requires an understanding of how well existing and potential future systems will performed in future climate. In this Thesis, we explored adaptation to climate change are system specific. Institutional infrastructure and System of Innovation (SI) in the coffee agroforestry systems of Kenya are different for different sectors. The case study on the coffee and dairy sectors of Central Kenya revealed that the system of innovation of the coffee sector emphasizes on technology development, and actors are concentrated at the production stage. The marketing and processing stage is dominated with few actors, who are powerful with information asymmetry with the lower level actors, and farmers are deficient in information about the market price of their product. The dairy sector, on the other hand, is mobilized by market orientation, where actors are equally concentrated at all levels of the value chain. The presence of different organizations, and market freedom, basically a producer center service delivery helped the system to attract others to come in.

This Thesis also demonstrated the important roles of the institutions, and how it affects the competitiveness of different sectors. The Thesis also emphasized on the push and pull factors for farmers transition from one sector to another and its impact on adaptation to climate change, and food security. This also demonstrated, why actors differ in their contribution to different types of sectors. This is an important contribution, where development partners could understand the gap, why some sectors are preferred by farmers and, why not other sectors. The comparative analysis, particularly in the innovation process of the coffee agroforestry systems opens-up to develop a methodology for analyzing the comparative advantages of the sectors.

Moreover, the concept of sectoral system of innovation (Malerba, 2007; Malerba, 2004; Malerba, 2002; Edquist and Chaminade, 2006; Breschi *et al*., 2003), which basically provides a multi-dimensional, integrated and dynamic views of sectors in general provide a key level of analysis for economists and technological innovationists in a multi-dimensional way. The framework of sectoral system of innovation, so far, however, has not been mobilized to analyze different sectors, such as climate change adaptation strategies in agriculture and other sectors, rather than characterizing the sectoral dynamism and firm technological diversification, particularly in the industrial sector. Methodologically, this Thesis, therefore, provides an insight to mobilize the framework of sectoral systems of innovation in climate change adaptation.

6.5. Contribution to learning, innovation and research process

This Thesis also contributes to the academia of learning, innovation and research process. Regarding to learning process, it contributes towards, what is known about climate change knowledge, adaptation strategies, and the roles of institutions in the adaptation process to climate change. This includes the knowledge on the advantage of agroforestry systems for adaptation to climate change, and contributing towards household food security. Actors and stakeholders in the agroforestry system are working towards innovation of the system. This Thesis identified the way actors interact and distribute in the coffee and dairy sectors. This helps to the improvement of the innovation process. For example, actors in the coffee and dairy, their performance and overall output are different. This therefore, helps them to use it as input. With the research process, the results of this Thesis could be important for the consumption of researchers in the field to better work in the improvement of the adaptation process.

6.5.1. Climate change knowledge: farmers and scientists perspective

Adaptation to climate change calls knowledge bases, seen as a direct corollary of knowledge on the effects of current or future climate change, and their interpretation by different parties, such as the farmers and scientists. The common problem is viewed to have different interpretations from different actors; scholars, such as (Yaro 2013; Ndambiri *et al*. 2013; Kemausuor *et al.* 2011), the importance of local farmers' knowledge and perception of climate change for adaptation. Climate change knowledge from scientists' perspective (Bromley-Trujillo *et al.,* 2015; Knutti & Rogelj, 2015; Steenwerth *et al,* 2014; Mugalavia *et al.*, 2008), finds how the scientific community interprets climate change using different models and complex mathematical framings.

Unifying the local people's approach with the scientific community approach, which integrates different interpretations, and understandings to a common problem of climate change, and climate change adaptation supports the academia to understand the need for future learning strategies. This research, therefore, brings in to the body of literature the comparative knowledge of climate change from both the local people's perspective and the way the scientists' approach in understanding climate change from historical perspectives. Unlike the dominance of scientific framing, the attempt to take in to account the farmers' knowledge and the interrelationship either in consistency and/or discrepancies is the contribution of this research.

Farmers' adaptation to climate change depends on their pre-determined perception; only farmers who perceive the climate is changing adopt adaptation strategies to climate change (Abid *et al,* 2015; Deressa, 2008; Maddison, 2006; Li *et al*., 2013). This Thesis, however, (1) unraveled a significant portion of the farmers who did not perceive a change was found to be using some adaptation strategies.This could be due to economic factors, such as income or other drivers, and it disproves the conclusion that farmers adopt adaptation choices if, and only if, they perceive changes. (2) Adaptation strategies and choices are farming system and agroecology specific; coffee farmers and food crop farmers adapt to climate change differently. (3) Off the number of options available in an area to implement to adapt to changing climate, some farmers apply multiple of choices, while other adopt single strategies. There is a positive relationship between adaptation to climate change and household income; the highest payoff/return achieves if multiple adaptation choices are used rather than a single strategy. These empirical results of this Thesis could be important for the academic and research community to understand the climate change knowledge, the adaptation options, their determinants and contributions from a new dimension. Viewing the knowledge of climate change from different actors helps the academia and research community to develop new ways of learning. Furthermore, this type of study, particularly, in the coffee agroforestry systems is important and it compares two zones of different farming system, which could be new in its kind. This opens-up a way scientists work to understand the capacity of adaptation of different systems, and helps the academia to understand the current situation and look forward for means of learning on adaptation knowledge.

6.5.2. Advancement in the innovation process to adapt to climate change

Policy makers and innovation scholars share an increasing interest to operationalize innovation support (Klerkx and Nettle, 2013), which is considered as process of co-production (Hartwich and Negro, 2010), and learning (Chhetri *et al.,* 2012). The sectoral innovation in the agroforestry system, part of this study identified sectors differ in innovation process and performance. The coffee development program for instance, was continued on technological development, such as diseases resistance new varieties, and agro chemicals, while the innovation in the dairy sector was mainly on infrastructural, and market facilities. These followed different value chain policy, and actors' participation, and interaction. These comparative case studies opens-up different stakeholders to understand the challenges and opportunities of the different systems. This Thesis, therefore, contributes towards the advancement of the innovation process through learning and experience sharing.

Capacity to innovate depends on the knowledge, and availability of representative framework in addition to financial, and material assets. Providing an extensive comparative analysis in the dairy and coffee sectors, which considers the difference in capacity to innovate, farmers and other actors' performance in their contribution towards the development of the sectors helps for the advancement of the learning and innovation process. This could be innovation capacity at the individual, institutional, or sectoral level.

6.5.3. Research process in climate change adaptation and farmers adaptive capacity

During the past decade, there have been a substantial increase in research on climate change adaptation, but a large gap remains to explore the strategies to improve capacity of actors in adaptation to climate change. Adaptation researchers have either failed to demonstrate the relevance of their findings to practitioners and policymakers (Klein and Juhola, 2014), or the stakeholder and practitioners haven't considered the information and knowledge of the researchers fits with their needs and interests (Jones and Tanner, 2016). Knowledge and use of actor-oriented results of adaptation research needs and options could serve to find ways to overcome the bottlenecks and narrow the gap between research and action.

In this Thesis, we have combined different knowledge and information sources for climate change i.e. the farmers' knowledge and perception, and the scientific methodologies to analyze the kind of scientific knowledge of climate change, and adaptation strategies at different levels, such as the household and institutional levels. This helps future research to emphasis on the kinds of knowledge and information stakeholders and adaptation actors are interested, the possibility of integration of different sources of knowledge of climate change for adaptation decisions. This Thesis also shed-lights the need to study adaptation from different perspectives and at different levels. It helps future research and development to consider not only the technical adaptation, but also the institutional innovation and reformation is equally important.

6.6. Implication for policy development

In relation to policy development, the contribution of this Thesis mainly refers to the triple components of adaptation policy. These are (1) farm level policies to improve farmers' livelihood and food security; (2) research policy, such as agronomic and socio-economic research; (3) policies on international agreements and negotiations of mitigation and adaptation to climate change.

6.6.1. Farming system based decisions

Recommendations specific to the agroecology and farming system typologies, needs different policy support. This considers the farmers' adaptation need, availability of adaptation choices, capacities to use such kinds of choices and the expected benefits from the adaptation strategies. This could have different options:-

1. Farmers' intensification of on coffee production through exhaustive implementation of technological innovation to improve production and productivity. This may solve the farmers' problems at production and marketing levels. This includes access to the right inputs at the right time. Technological innovations to develop coffee varieties, which are diseases and drought resistant but also socially and economically viable. Technical application of agronomic and other forms of adaptation strategies to improve

production and productivity. Marketing arrangement and improving the value chain is the other form of innovation, which solve the problem. Institutional arrangement and actors participation for the development of the coffee sector plays an important role. The supply chain and institutional arrangement of the dairy sector could be an example for the coffee sector. This includes participation of different actors at different levels of the supply chain, information symmetry throughout the chain and price and other negotiations. This is both farm level and sector level changes.

2. At times scenario number 1 fails; farmers need to diversify from specialized coffee or food crops to dairy provided that the dairy sector continues encouraging. This option helps farmers to diversify their income sources in order to adapt to climate and other challenges. Coffee-food crop diversification is recommended for farmers with the objective of risk aversion and intending food self-sufficiency or supplementing consumption by own production. The diversification towards dairy production, on the other hand, the initial investment cost to buy a cow. The farmers' capacity of purchasing power of cow and access to feed and dairy meals determine the farmers' diversification to dairy.

3. The sectoral transformations in the coffee agroforestry system have its push and pull factors. The challenges in the coffee sector, such as the land use change due to infestation of diseases, and droughts discourage farmers to stagnate in the traditional coffee farming on one hand, and the access to inputs and production technologies, availability of emerging market and negotiations for assured prices of dairy products, on the other hand, encourages farmers to completely switch from a traditional coffee production the emerging business of dairy sector. Farmers of this category are commercial oriented dairy producers with better access to dairy technologies, market, and feed to their livestock. Comparatively, dairy specialized farmers are those have capacity to have higher number of cows as a function of reduced milk production cost per liter.

6.6.2. Research on system of innovation for climate change adaptation

Advances in the science and observation of climate change are providing understanding of the inherent variability and changes, which is likely dependent of the mitigation and adaptation actions. This mitigation and adaptation actions will depend not only on the response of the farm level, but also on the institutional and policy actions. The research and innovation policy in the area of climate change and climate change adaptation plays a key role. Policy guidelines towards agronomic and socio-economic researches, technological development, and institutional arrangement for adaptation to climate change adaptation is equally important as the technical perspectives. So far, such policies have not adequately considered the research and innovation policy, which are crucial possibilities, such as climate change mitigation and adaptation. This Thesis could be an important input for the consumption of research and innovation policy actors.

6.6.3. Input to policy on international agreements and negotiations

In the COP 21 (21st Conference of Parties of the United nations Framework Convention on Climate Change, UNFCCC 2015), Paris agreement, for instance, countries have agreed to develop National Adaptation Plans (NAP). One of the discussions and agreements of Paris agreement of Cop 21, 2015 of the conference of parties of the UNFCCC was to develop a framework for financial support of adaptation to climate change. Agricultural countries like Kenya submitted their Intended Nationally Determined Contributions (INDCs) mainly to use the natural resource base of farming systems sustainably as their means of adaptation plan. These countries proposed the main source of emissions is from agriculture, forestry, and land use systems. Agroforestry, on the hand, is potential for the mitigation and adaptation to climate change. Developing countries proposed emission abatement as their NAPs. Payment for adaptation strategies and other financial assistance particularly to developing counties is based on ecosystem management. This, however, requires negotiations, where developing countries have to be incentivize for their agroforestry maintenance. These targets as part of the NAPs demand a framework and guideline, which depends on a body of literature in order to helps the process of implementations of the strategies. The studies by IPCC are majorly use for such decisions.

For policy consumption, the studies by IPCC, (IPCC, 2001; IPCC, 2007, IPCC, 2013), and other studies at individual or group level, such as, (Mugalavia *et al*., 2008; Rosell and Holmer, 2007; Patricola and Cook, 2010) uses annual rainfall. Annual rainfall is, however, misleading, unless the patterns, such as onsets, offsets, intensity, frequency, and inter-annual variabilities are considered. This Thesis, therefore, contributes towards the contribution of the consideration of rainfall patterns beyond the simple analysis of annual variabilities of rainfall, which is important for crops and animals production. This is related to the study of agronomic drought, rather than looking at the hydrological drought.

6.7. Future Research

The adaptation steps and strategies exhaustively studied in this Thesis are the behavioral and attitudinal change towards adaptation, on-farm choices derived directly from survey, and analysis of system of innovation of the coffee and dairy sector at institutional level. However, in the context of climate change, other strategies, such as new infrastructural development, institutional subsidies, voluntary participation towards community and other activities are likely to be important. The options to incentivize farmers, such as payment for ecosystem services in order to adopt adaptation strategies and farmers' willingness to pay for adaptation strategies are important future research topics.

Estimation of the implications of the adaptation choices to household economic values such as income could be important for policy decisions. But, methodologically, the simple comparison of incomes received from adoption of the choices taking an annual income of one year may be insufficient to understand the co-relation of the choices and their contributions, and if this co-relation is yielding some system transitions. Future research is, therefore, needed to further understand the underlying factors that define farmers' choices and their implications.

Furthermore, beyond the study of the current way of actors' interaction, coordination and contribution towards coffee and dairy sectors, the potential for better adaptation to climate change and the household food security is another important research topic.

The household level adaptation strategies, which consist of behavioral and attitudinal change towards adaptation, practical implementation of choices and support services from institutions. Among the technical adaptation strategies, farmers intensification on coffee, diversification to dairy, shift from coffee to a complete specialized dairy production are exhaustively included in this research. Migration and off-farm participation, which are very important elements of adaptation strategies for households are however, not covered in this Thesis. These key adaptation strategies could be important future research topics.

The value chain and institutional innovation part of this Thesis discovered that push and pull factors determine the performance competitiveness of sectors. The dairy sector, in addition to the fairly distributed actors interaction and market reasons, it is fairly protected by the policy, while such actions are unlikely in the coffee sector. A further research on policies of subsidies, protection, and engagement of different sectors could have paramount importance. This could analyze the weak and strong sides of all sectors in order to have lessons between sectors.

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APPENDICES

Appendix 1 Conference Communications

1.1. Climate Smart Agriculture (CSA 2015), Poster presentation

CLIMATE-SMART Agriculture 2015 Global Science Conference

March 16-18, 2015

Le Corum, Montpellier France

Climate smart strategies to strengthen coffee farmers adaptive capacity to climate change

Asayehegn Kinfe[1], Temple Ludovic[2], Iglesias Ana[3], Pedelahore Philippe[4] and Triomphe Bernard[2]

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Abstract

Adaptation of the agricultural sector to climate change(CC) is a main concern for the scientific and farmers'. Farmers and scientists perceive CC and adaptation needs differently. This work explores:

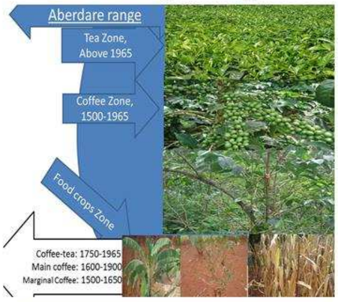
1) The views of scientists and farmers on adaptation needs.
2) Farmers' perception of CC, farm level adaptation strategies and the implications of climate smart agricultural practices (CSAPs) on household income.

The results show:

- Farmers' adaptation depends on their perception of the occurrence of CC, the need for adaptation, and the potential benefits for implementing new production strategies.
- Adoption of complementary multiple strategies have a higher payoff/return over adoption of particular adaptation strategies in isolation.

1. Introduction

- Coffee production in Kenya has declined by almost 65% in the last 30 years, and as much as 5 times in Murang'a County, a major coffee producing area. At the same time, coffee has moved up: whereas it was grown at altitudes of 1200-1500 m until 1980s, today it is grown at altitudes above 1500m, and between 1600-1900m for optimal production. lower altitude coffee area is converted to food crops and in the mid altitude potential coffee area, diversification to dairy is becoming common.



2. Methods

1. 120 farmers equally stratified to food crop and coffee production were interviewed about their perception of climate change. Consequently, 84.2 and 36.7 percent observed extended drought and extended cooler seasons respectively while 88.3 and 89.2 percent perceived changes on onset and cessation of RF respectively.
2. Official rainfall and temperature records for Murang'a were collected and analyzed for trends over the 1980-2012 period.
3. CSAPs adopted by farmers and their impact on household income is explored. Coffee farmers and food crop farmers are found to have different strategies to adapt CC.

3. Results

a) Farmers' Perception of CC (Table 1)

Perceived changes	Coffee zone		Food crop zone		Total		χ^2
	Freq.	%	Freq.	%	Freq.	%	
Extended warmer seasons	48	80	56	93.3	104	86.7	4.615**
Extended drought	44	73.3	57	95	101	84.2	10.568***
Extended cooler season	32	53.3	12	20	44	36.7	14.354***
Change in onset of RF	51	85	55	91.6	106	88.3	1.294
Changes in cessation of RF	51	85	56	93.3	107	89.2	2.157
Changes in duration of RF	48	80	56	93.3	104	86.7	4.615**
Changes in intensity of RF	50	83.3	56	93.3	106	88.3	2.911*
Changes in frequency RF	50	83.3	56	93.3	106	88.3	2.911*
Inter annual variability RF	48	80	56	93.3	104	86.7	4.615**
Predictability of RF	49	81.6	56	93.3	105	87.5	3.733*

*<0.1, **<0.05, ***, 0.01, RF=Rainfall

- Food crop and coffee farmers perceive climate change differently.
- The analysis of farmers perception indicates climate change (patterns of rainfall and variability of temperature) is higher in the lower altitude food crops zone except observation of extended cooler seasons than in the upper altitude coffee zone(Table 1).

b) Observed changes in annual temperature and rainfall (1980-2012)

Figure 2: Annual temperature difference in Celsius

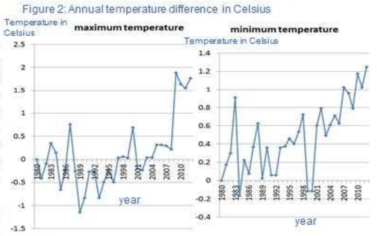
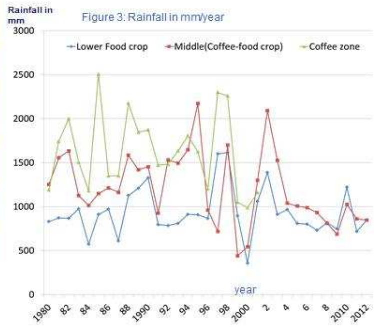


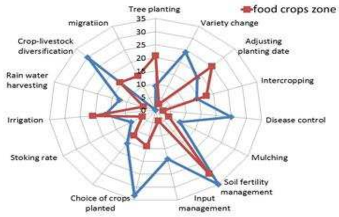
Figure 3: Rainfall in mm/year



- Maximum and minimum temperature increased by 1.76 ºC and 1.25 ºC (figure 2) between 1980 and 2012 respectively, and are projected to increase further by 1 ºC and 2.3 ºC by 2020 and by 2050 (CIAT, 2010). Such increase is in line with farmers' perception of CC (see Table 1).
- Measured annual rainfall(RF) (figure 3) decreased slightly over 1980-2012 periods. This contrasts with farmers' perceptions that RF decreased significantly over the last decades. The change perceived by the farmers, but not confirmed by the scientists could be a change in RF pattern(onset, cessation, frequency, intensity, or seasonality of RF)

c) Adaptation: Climate smart practices

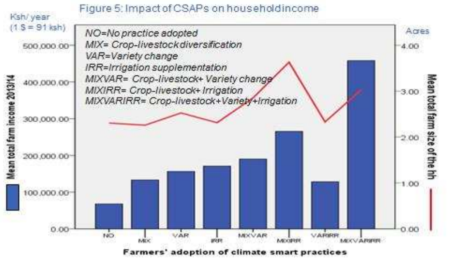
Figure 4: adoption of adaptation strategies to CC



- Farmers adopt a range of adaptation strategies in response to perceived CC(figure 4).
- Crop management strategies such as changing varieties, choices of crops, input management and diseases controlling are mostly practiced by coffee farmers (figure 4).
- tree planting and shed management, adjusting planting dates, irrigation and migration are mostly practiced in the lower altitude food crops

d) Effects of climate smart practices on household income

Figure 5: Impact of CSAPs on household income



- Non-adopters of strategies are found to have less annual income by 60,565.25*Ksh* compare to adopters .
- irrigation adoption yields higher income followed by varietal change and mixed crop-livestock diversification respectively among adoption of single strategies in isolation.
- Farmers adopted all the three strategies (MIXVARIRR) have better income than single strategy adopters, for instance are more wealthier by 325,255.82 and 287,340.70Ksh compare to crop-livestock and irrigation adoption in isolation.

4. Conclusion

- Farmers overestimate the decline in rainfall; probably since rainfall is a key factor for optimal harvest and is affected more by pattern which is less considered by scientists.
- Adoption of multiple adaptation strategies increases total farm income. Simultaneous adoption of crop-livestock diversification, changing varieties and irrigation provides the highest payoff in compare the other strategies in isolation and combination.
- The next steps of research will include analysis of suitable location of coffee areas taking into account CSAPs.

Acknowledgements

The study was supported by the EU under the PhD programme AGTRAIN, ICRAF Nairobi(AFS4Food project) and CIRAD.

1.2. Workshop on Study of Family-run Farming
"Theoretical Framework for Comparative Analysis on Family Farming"

March 17-18, 2016 at Kyoto University
Venue: Large Conference Room (C102), Faculty of Agriculture Main Bldg., Kyoto University

Presentation mode: Oral presentation

Innovation and Transition in Family Farming: How dairy farming is emerging in the coffee agroforestry systems of Central Kenya

Kinfe Asayehegn[2], Ludovic Temple[3], and Ana Iglesias[4]

Abstract

Emerging challenges to farming drives farming systems to have three strategies; intensification options optimizing resources and technological innovations, firm diversification orchestrating interdependencies among sectoral boundaries, and transition to new system and trajectories. The intensification in the coffee system is the research supported innovation process to specialize in coffee using new varieties and practices while the second option is diversification to complementary enterprises (emphasis equal attention to coffee and dairy farming) to adapt climate and other challenges. The trajectory shift emphasis on how new sectoral systems (dairy sector being a community and private sector derived innovation) emerges, and what is the link with the previous sectoral system (coffee sector) in terms of impact pathway on the effective and efficient transformation of inputs into products and eventually result in impacts. In the multi-level perspective however, there is no simple cause effect relationship drives transitions rather systems change is enacted by various types of actors, such as producers, policy makers, researchers, and privates. This paper, therefore, presents (1) how (why) the transition from coffee to dairy based farming system in the coffee agroforestry systems of Murang'a County, central Kenya is taking place? (2) How the different actors in the innovation system of transition contribute to the learning and

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innovation process? And (3) what contributes the transition from intensified coffee based to dairy based farming system on household food security? Our data collection consists of three sources. Household survey (120) for household specific data, focus group discussions (9 FGDs) to characterize the transition and innovation process and stakeholders' interview (15 interviews) for understanding the contribution of stakeholders in the transition and innovation process.

Coffee production in Kenya has declined by 65% in the last 30 years, and as much as 5 times in Murang'a County, a major coffee producing area. The dairy sector is, however, in opposite visualizing sharp increase in volume of production and price. This leads to three pathways of change. The first option is the reproduction and intensification on coffee which follows an incremental change on the way farmers practice to the full system of coffee practice (practiced by only 13 percent of the faring community). Second option, the system of diversification that includes both the coffee and dairy in a specified and limited asset ownership but optimization the resources for better use and the third option used by the farmers to cope up with the challenges is the discontinues shift from the coffee based system of production to intensified dairy business. The study further finds that innovation process and actors' interaction differs for the coffee and dairy based systems. Actors in the coffee are limited, the system is highly centralized with limited options to farmers to process and market their product while the dairy sector is less informally controlled by demand based business, comparatively numerous actors with limited government intervention, various options to process and marketing products. Exponential increase in production cost which is a function of coffee diseases and institutional failure (financial and none financial) of the coffee sector while strong public and private intuitions are emerging in the dairy sector is the other driver of the transition. The study further finds that transition from coffee to dairy based farming system have higher annual return by an average income of 325,255.82 KES. We, therefore, conclude, the strong correlation between farm performance and socio-institutional variables, stakeholder interaction suggests the need for the establishment and strengthening of local institutions such as micro-finance and extension that have capacity to break the farmers' capital constraint to invest which is beneficial to sustain systems and facilitate transition if required.

Keywords: Coffee agroforestry, Emerging challenges, Family farming, Innovation, Transition

1.3. Forum Innovation Conference

Presentation mode: Oral presentation

Institutional Innovation and Sectoral Transition

Kinfe Asayehegn[a,b,c], Ana Iglesias[c], Bernard Triomphe[b], Ludovic Temple[b]

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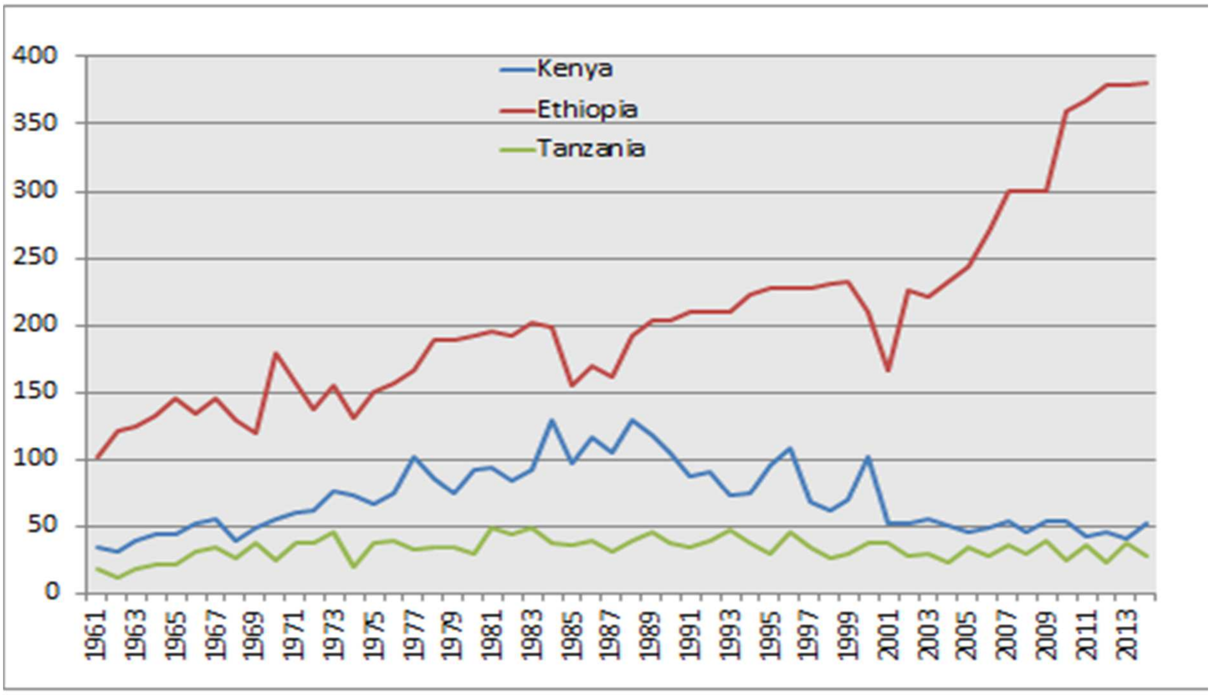
Abstract

This paper explores the roles of institutions in driving options to adapt to CC and claims the sectoral innovation performance depends on the performance of institutions and actors interaction. We identified two sectors that differ in terms of actors involved, enabling environment and institutional and organizational setup, i.e., (1) technological and institutional innovation to specialize on coffee, and (2) innovation towards the development of dairy sector. And the results finds that (a) Actors in the coffee are limited, the system is highly centralized with limited options to farmers to process and market their product while the dairy sector is informally controlled by demand based business, comparatively numerous actors, (b) The innovation in the coffee sector was on the technology development, while the dairy sector was mostly on institutional building. The comparison on the contribution of different farming systems to food security finds that specialized dairy farms have higher income and expenditure on food while diversified coffee-dairy farmers have higher dietary diversity.

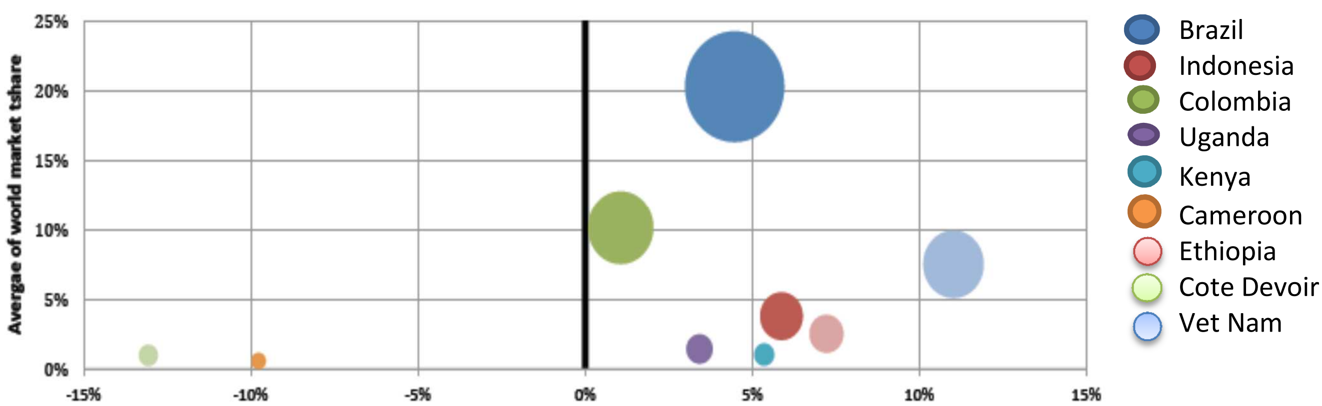
Keywords: Coffee sector, dairy sector, institution, innovation, Kenya

Appendix 2 Coffee production per year in three East African countries



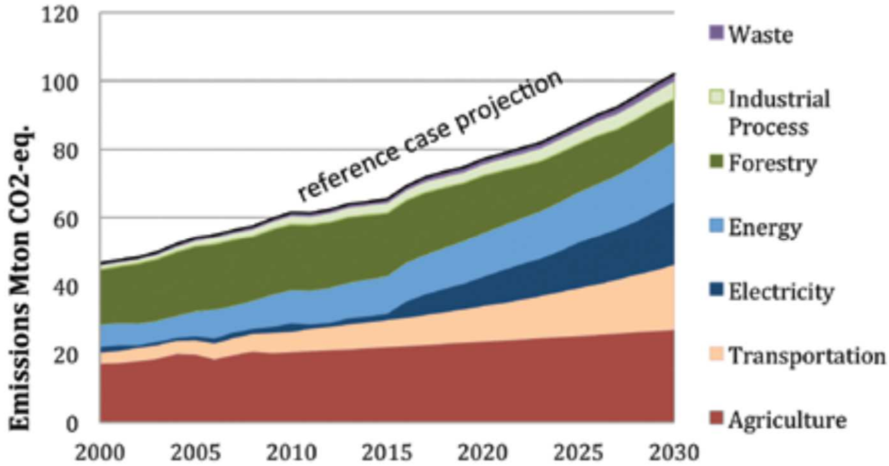
B. Trends in Kenyan coffee production in compare to Ethiopian and Tanzanian coffee production from 1960/61 to 2013/14 ('000', 60 kgs).

Source: FAOSTAT and USDA foreign agricultural services online database, [https://apps.foas.**usda**.gov/psdonline](https://apps.foas.usda.gov/psdonline)



Trends of coffee export values (size of balls), market share (y-axis) and relative growth in comparison to world production (x-axis) (2000-2011) (Source: Comtrade)

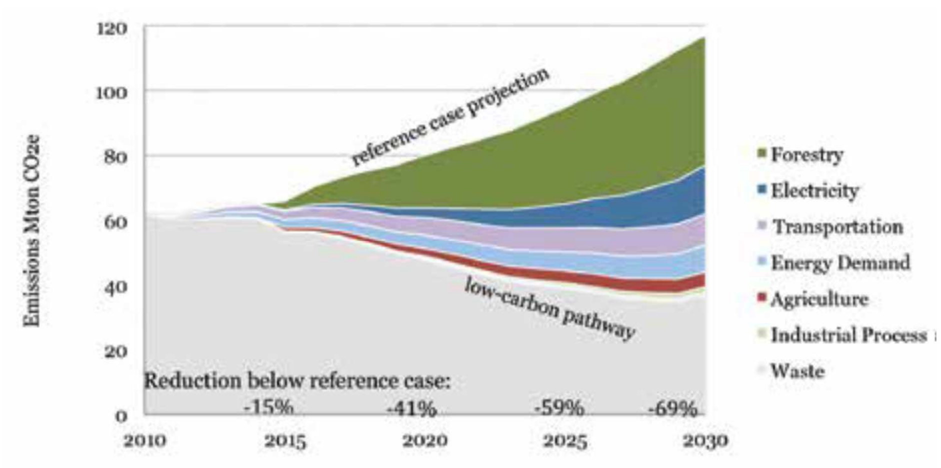
Appendix 3 Climate Change Scenarios: GHG emissions reference case, 2010 to 2030



Source: GoK CCAP Mitigation Analysis 2012

B. Composite abatement potential for all sectors (technical potential) in Kenya

Source: GoK CCAP Mitigation Analysis 2012



Appendix 4 Minimum and maximum temperature trend from 1960-2010 (Data courtesy of KDM)

Region	Minimum temperature		Maximum temperature	
	Trend	Magnitude	Trend	Magnitude (C^0)
Western	Increase	0.8-2.9	Increase	0.5-2.1
Northern and north-eastern	Increase	0.7-1.8	Increase	0.1-1.3
Central	Increase	0.8-2.0	Increase	0.1-0.7
South-eastern	Increase	0.7-1.0	Increase	0.2-0.6
Coastal	Decrease	0.3-1.0	Decrease	0.2-2.0

Source Kenya NCCSR and KDM, 2010

Appendix 5 computed analysis of adaptation measures

1. Information on climate changes and forecasting	**Answers (Weighting value)**	**% (N=220)**
1.1. Do you frequently use information on weather and climate?	Yes(1)	48.18(128)
	No(0)	51.82(92)
1.2. In some cases local elders observe at different indicators to forecast the onset of the rainfall. Are you one of such kind of people or do you use such type of indigenous means of weather forecast?	Yes(1)	52.28(115)
	No(0)	47.72(105)
2. Climate change perception	**Weighting value**	**% (N)**
2.1. Do you personally think the climate in general has changed when you compare the way it is now and the way it was in the past?	Yes (1)	86.82 (191)
	No(0)	13.18(29)
2.2. Given the climate has indeed changed as you responded in 2.1., how do you explain the rainfall comparing the current with past?	Increased(1)	2.73(6)
	Decreased (-1)	84.09(185)
2.3. Given the climate has indeed changed as you responded in 2.1., how do you explain the temperature?	Decreased(1)	10.45(23)
	Increased(-1)	76.36(168)
3. adopting climate change adaptation	**Weighting value**	**% (N)**
3.1. Given your response for 2.1. above, the climate has changed/or no. Have you done something, therefore, in the way you farm?	Yes (1)	72.27(159)
	No (0)	27.72 (61)
3.2. During some years, you might expect pattern of rainfall to be out of the normal. In such cases have you practiced **variety change**?	Yes (1)	33.18(73)
	No (0)	66.81(73)
3.3. During some years, you might expect pattern of rainfall to be out of the normal. In such cases do you **adjust your planting time**?	Yes(0)	48.63(107)
	No(0)	51.36(113)
3.4. Have you practiced intercropping or change the way the pattern of different crops?	Yes (1)	43.18(95)
	No (0)	56.82(125)
3.5. Have you practiced **shifting crops between**?	Yes (1)	24.09(53)
	No (0)	75.90(167)
3.6. Have you introduced new way of diseases control?	Yes(1)	35.00(77)
	No(0)	65.00(143)
3.7. Have you practiced **shifting feeding strategy** of your livestock?	Yes(1)	45.50(100)
	No(0)	55.50(120)
3.8. At unfavorable years such as a year with	Yes(1)	20.00(44)

droughts, do you decrease the **stocking rate** of your livestock?	No(0)	80.00(176)
3.9. Have you **planted new trees** or changed the way you manage trees?	Yes(1)	38.18(84)
	No(0)	61.81(136)
3.10. Have you introduced **irrigation**?	Yes(1)	39.09(86)
	No(0)	60.90(134)
3.11. Have you introduced any form of **crop-livestock mixed** farming?	Yes(1)	48.18(106)
	No(0)	51.81(114)
3.12. Did you use **farming and offarm** activities at the same year?	Yes(1)	33.18(73)
	No(0)	66.81(147)
3.13. Have you had **temporary or permanent migration** of at least one member of your family for the search of job?	Yes(1)	14.09(31)
	No (0)	85.90(189)
4. Household characteristics	Answer	Mean value
4.1. **Gender** of the household head	Male(1)	64(141)
	Female(0)	36(79)
4.2. Age of the household head in years	Open	58.03
4.3. **Family size** of the household head in adult equivalent	Open	3.58
4.4. **Education level** of the household head in years	Open	6.47
5. Household's resource endowment	Answer	Mean value
5.1. How big is your farm in acres?	Open	2.60
5.2. How much annual income in'000' USD have you earned from **off farm** sources during the year 2013/14?	Open	0.91
5.3. How much annual **farm income** in'000' USD have you earned during the year 2013/14? (We first listed all the farm income sources of the household and the approximate KES)	Open	1.91
5.4. How many **livestock** do you have currently? (all values given here are in TLU)	Open	
5.5. What is the **distance** between your home/farm to the nearest input market in KM?		4.86
6. Institutional setting	**Weighting value**	**%(N)**
6.1. Do you have access to **credit** for your farming?	Yes(1)	61.82(136)
	No(0)	38.18(84)
6.2. Do you have access to **extension** / advisory services?	Yes(1)	38.18(84)
	No(0)	61.82(136)
6.3. Are you a member of to at least one cooperative?	Yes(1)	69.09(152)
	No(0)	40.91 (68)

7. Access and use of farm inputs	Weighted value	%(N)
7.1. Have you introduced **manure** use or changed the way you do on the farm?	Yes(1)	82(197)
	No(0)	18(23)
7.2. Have you introduced or changed the way you do **mulching** at your farm?	Yes(1)	25(55)
	No(0)	75(165)
7.3. Did you produced compost on the farm or changed the way you use **compost** in your farm?	Yes(1)	20(44)
	No (0)	80(176)
7.4. Given that **fertilizer** is important for crop production, do you often use it?	Yes(1)	100(220)
	No(0)	0(0)
7.5. Do you have access to improved seed of crops?	Yes(1)	100(220)
	No(0)	0(0)
8. Agroecological zone	**Weighted**	**% (N)**
8.1. Agroecological **zone** where the household lives	Coffee(1)	120(50)
	Food crops (0)	120(50)

Appendix 6 Definition and summary statics of the variables used in the analysis

Variables	Mean value for all adaptation strategies(independent variables)									Mean total
	Variable description	**NO**	**MIX**	**VAR**	**IRR**	**MIXVAR**	**MIXIRR**	**VARIR**	**MIXVARIRR**	
Household characteristics										
GENDER	1=if the head is male	0.48	0.62**	0.80**	0.50	0.68**	0.73**	0.60**	1.00***	0.64
FAMSIZE	Family size(number)	3.39	4.07	3.50	3.33	3.42	3.91	2.90	3.66	3.51
HHEDU	Education level of the head in years	6.96	9.23**	8.00*	8.58*	8.94***	8.91**	7.80**	11.4***	8.47
Resource constraint										
FARMSIZE	Farm size in hectare	2.31	2.26	2.52	2.31	2.85	3.63**	2.33	3.03*	2.60
INCOMFARM	Annual farm income in'000' KES	67.8**	13.9***	156.3*	170.8***	189.9***	265.5***	128.3**	458.2***	174.1
TLU	Total livestock(in TLU)	1.25**	1.61	1.23	1.69*	1.75*	2.00***	1.62	2.04***	1.59
DISTANCE	Distance to market in Kms	5.45	4.15	4.05	6.00	5.00	3.82	4.90	4.25	4.86
Institutional										
CREDIT	Have access to credit=1	0.42**	0.23	0.70***	0.75**	0.84***	0.64**	0.60**	1.00***	0.62
EXTENSION	Have access to extension=1	0.27	0.08	0.40	0.58*	0.53***	0.45***	0.100	0.75**	0.38
Climate and climate information										
PERCEPTION	Perceived climate change=1	0.91	0.85	0.80	0.92	0.95	1.00	0.90	0.92	0.91
INFORMAT	Have access to information=1	0.42**	0.54	0.60**	0.75***	0.53	0.45	0.80***	0.92***	0.58
TRADKNOW	Access to traditional weather forecast	0.39*	0.54*	0.70	0.50	0.50**	0.55	0.60	0.50	0.52
Other variables										
EXPERIMENT	Experience in experiment and trying new things=1	0.42	0.74**	0.40	0.50	0.74**	0.55	0.50	0.67	0.56
MANURE	Prepare and use manure=1	0.24***	0.38	0.50	0.67**	0.53	0.73**	0.30	0.58**	0.45
COMPOST	Prepare and use compost=1	0.15	0.38***	0.00***	0.08**	0.26	0.18	0.10	0.42	0.20
MULCHING	Use mulching=1	0.21	0.31	0.30	0.08	0.42	0.27	0.10	0.25	0.25
ACCESHED	Coffee under shed=1	0.09	0.00	0.30***	0.17***	0.26	0.09	0.10**	0.42***	0.17

Appendix 7 Data collection Instrument: Focus Groups Discussions (FGDs) Checklist

Survey Checklist *(Farmers' FGDs)*

Research Topic: Impact of Climate Change on the Agro-Ecological Innovation of Coffee Agroforestry Systems in Murang'a, Kenya

Kinfe Asayehegn, GEBREEYESUS

A. Coffee production and Management

1. What coffee varieties do you have in your farms currently? Do you use the old variety (SL or K7)? Do you use the new varieties (Ruiru 11 and/or Batian)? If yes, since when? Why did you start the Ruiru 11 and/or Batian?
2. What differences in terms of benefits (income), productivity(product per unit area), product prices and market acceptability, input costs (fertilizer, pesticide, and herbicide), labor costs (costs for managing and harvesting) have you observed between the old varieties of SL and the new varieties of Ruiru 11 and Batian? Which one do you prefer now? Why you prefer it?
3. From whom did you first learn about the Ruiru 11 and Batian varieties? Where did you get the seedlings at the time of your start? If you don't use the Ruiru 11 and Batian, what is the reason? If you had/have once but you can't expand/continue it, why it is happened?
4. Do you face any problem with the old or new varieties? If yes, what problems to which variety in particular? Have you tried to solve the problems/has any one or organization tried to solve the problems you have in the coffee varieties? Who? How? What was/is the solution to it? What do you suggest as a solution to the problems of the varieties you have explained? A Table will be prepared for details.
5. Have you sufficiently adopted the Ruiru 11 and Batian? If no, why? What are the limiting factors hindering you to adopt the new varieties? If yes, what benefits you imagined before to adopt the new varieties? Have you got it as you imagined? If not, what differences have you got after you have adopted? To analyze supply and demand
6. Do the CRF and other organizations ask you for feedback either to improve or to know the real problems you have especially on the coffee varieties?
7. Have you ever faced a problem in your coffee farming? How did you first learn what this problem was? Did any person/ organization/ training help you to identify the problem you have and help in finding a solution? If yes, who? What would you do if you face the same problem today/in the future? Have you developed a capacity that you could identify the problem and its solution?

8. Do the stakeholders in coffee involve you in research and dissemination process? If yes, who initiated the agenda of collaboration? How and why? What was your role in the process?
9. Have you taken any training related to coffee management? If yes, what was the training about? Who provide it to you? How related was it to your problem? What the training helped in getting solutions to your problem? Have you made any change in your farming as a result of the training? What changes have you made exactly? Why?
10. Do you actually use / implement recommendations directly from CRF and other actors? If not: Why not? What limiting factors do you have? What factors have contributed to the adoption/not?(in appropriate to the real problem, the case is not the priority, better technology availability, none workable innovation, extra consequence of the innovation, failure in extension and dissemination, cost-benefit unmatched, social factors, political factors, institutional barriers, other economic factors) the points in bracket are guidelines
11. What do you suggest the government and other organizations for having better varieties of coffee that could enhance the coffee sector development?
12. What do you think about the coffee production trends for the last 15-20 years (increasing, decreasing, remains constant, and fluctuating)? If continuously decreasing, what do you think are the major problems/challenges/constraints of the sector? General question

B. Intensification on coffee Vs Diversification to livestock Production

1. Has your management of coffee changed over the past 10-15 years or so? If yes, what do you do differently today compared to 10-15 years before (technical management of intensification, diversification to livestock and offarm activities, and a progress to totally transform to nonfarm)? Why did you do so? If no to the above question, why? to explicitly understand the determinants of change
2. At times coffee profitability decreases, what happens to your coffee management (input use, labour use, portion of land allocated to coffee, concentration on coffee management vs shifting to other enterprises)? A Table will be used for presentation of answers
3. At times coffee is no more profitable, do you do any change in your income source, activity, livelihood option? What do you change exactly? Addition explanation during discussion
4. What makes you to shift/diversify from intensified coffee production to livestock and other sectors? What are the limiting factors in the former intensification on coffee? What are the motivating factors from the animal/other sectors other than the coffee sector? In case diversification to livestock or other enterprise is mentioned above

5. Would you tell us the story of livestock in the area (type, trends and breeds you had/have, herd size, productivity? Is there any change in livestock holding and management 10-15 years before and now? If there are changes, what are? Why this happened?
6. Do you get support for improved livestock production technologies (breeds, feed, AI, vaccine, market infrastructure)? If yes, what supports and who provides it to you?
7. Did you adopt any of the improved technologies in livestock mentioned above? What factors have contributed to the adoption/not?(in appropriate to the real problem, the case is not the priority, better technology availability, none workable innovation, extra consequence of the innovation, failure in extension and dissemination, cost-benefit unmatched, social factors, political factors, institutional barriers, other economic factors) the points in bracket are guidelines for the interviewer
8. Do you use AI/the bull for your cows? Why? When did you start? Where do you get the AI? Who informed you to use the AI? What is the importance of using AI over bull?
9. Do the stakeholders in the livestock involve you in research and dissemination process? If yes, who initiated the agenda of collaboration? How and why? What was your role in the process?
10. Have you taken any training related to livestock/feed/products management and marketing? If yes, what was the training about? Who provide it to you? How related was it to your problem? What the training helped in getting solutions to your problem? Have you made any change in your farming as a result of the training? What changes have you made exactly? Why?
11. What major changes/benefits have you obtained due to your diversification or changing to livestock production(input supply and use, Improved animal breeds, improved natural resource management, better cash, better living condition, decreased risk, better access to education, self-employment, increased business activities such as local canteen, shops, taxi and boda boda renting, savings and assets, formation of institutions such as Table banking,) the points *in bracket are guidelines for the interviewer*

C. Rules, regulations and policies

1. Are there rules and regulations to your coffee production? What rules/regulations/policies do you know? When these regulations are started? Any new rules and policies recently started/unworkable? Rules to input use, production, management, marketing, processing of coffee?
2. Are there rules specific to the new/old varieties of coffee? What are they?

3. Are there any rules to dairy production, feed use, breeds use, marketing and processing? If yes, when these regulations/policies are started?
4. Any new institutions/organizations/enterprises on coffee/dairy established? Why and when they established?
5. How was the information on coffee flow? Is there any change before and now? With whom you are interacted for your information on coffee and dairy? If possible, diagram?
6. Any social networks created in the coffee/dairy sector? User groups, cooperatives, societies,
7. New technology established? Where do you sale/process your milk/feed?

D. Capacity to innovate and future prospects

1. How do you learn about new ways of doing things, problems and solutions, applicability and adoptability/adaptability of technologies/products?
2. Do you inform/make know other actors about your needs? How do you do it? *Brief explanation will be provided at the discussion*
3. How do you know what inputs (fertilizer, seed, seedling, spray chemicals, feed, AI) are important for your farming? How do you know where you can get them? What about their application? Training, projects, working groups, occasional study circles? *Consider points from government, NGOs, private sector differently*
4. Are you able to identify problems and opportunities on your own? Is there anybody that helps you in doing it?
5. Do you take risk and experiment with social and technical options at your own? Is there anybody that helps you in doing it?
6. Are you able to mobilize resource to effective support projects on your own? Is there anybody that helps you in doing it?
7. Are you able to link with others, share, and process relevant information and knowledge together for improving farming at your own? Is there anybody that helps you in doing it”?
8. How do you foresee / imagine the future of the coffee/livestock sector?
9. Do you have any plans to change something in your way of working in relation to climate change? For example: Will you 1) technically innovate, 2) diversify enterprises, activities and incomes, 3) Shift to nonfarm activities and incomes? Please explain your rationale for doing so? *The three lists are guides for the interviewer*

THANK YOU FORYOUR TIME AND DETERMINATION

Appendix 8 Data Collection Instrument: Coffee Farmers' Household Questionnaire,

Date of interview ____/___/____, HH Identification Number (code) ______ **Name**: _________________________________County: **Muranga**, sub county_________________, Location ______________________, Sub Location ________________________ Altitude ________________, GPS coordinates ________________________________ Farming system ___________________________________

(Upon arrival) Introduction of research objectives & research team + agenda

Quick tour of the farm with the farmer (max. 45 mn incl. questions)

During the tour, take note of main crops and if they look well managed, ask about own land + rented land, ask for explanations / rationale when seeing interesting crops or practices, fill in management practices for coffee & main crops (see pages 9-11). In general prepare the farmer (and yourself!) for the upcoming questions.

A. General information about the household and the farm

1. Years since establishment ____________ (as autonomous farmer)
   Farm Size (acres) a. own land _________ b. rented land _________ c: Total ______
   how many plots? ________________ (based on field tour prior)
2. What are your main productions (trees, crops, animals): 1: ______________ 2: _________________ 3: __________________
   (in order of importance) 4: _________________ 5: _________________,
3. What animals do you raise? Cows ____ Calves ______ Goats____ Sheep_____ Pigs ____Chicken ______ Others _______
4. Family & family labour (*start* by listing those who work on the farm, *then list* any other family members who also live on the farm or depend on it for their livelihood – *only then fill the other columns*)
5. Marital status of HHH 1=Married, 2=Single, 3=Widowed, 4=Divorced, 5=Separated, Gender: ____________
6. How many grown-up children do you have that live independently from you today? ___________

Name of HH Member	Status	Sex	Age	Education (years)	Lives in the homestead	time spent farming			Off-farm job? yes no what is it
						Full time	Part-time	Not involved	
1.	HHH								
2.									
3.									
4.									

5.									

7. Do you hire temporary labour to help you with your farming? No Yes
   If yes: for which activities / crops? ____
   how often? ____
8. Are you a **member of a cooperative or any other organization related to farming**? 0. No 1. Yes
   If yes, which one(s)? ,____? **Position** you occupy? ______________________________________
9. Access to **irrigation**? No Yes if yes, the type____
10. Distance to most common **input market** in KMs ______ time _________ minutes (access: walking public transport own transport)
    Distance to most common **produce market** in KMs? _______ time _______ minutes (Access: walking public transport own transp.)

11. Do you have **access to credit** for your farming when you require it? No Yes
    Do you use it every year? ____________________________
12. Do you have **access to extension / advisory services**? No Yes,
    If yes, what types of advice / services? ____
    who provides it to you? ____
    How important / valuable is this advice to you? ____
13. History of the farm (See page 9)

After having produced the cards, take a photograph and write down results carefully on page 9, so you can use it as reference throughout the interview

14. Production & related INCOME CONTRIBUTION for Year 2013-2014 (Mid-2013 to Mid-2014)

***Instructions**: Star first by selecting up to a maximum of 5 main income sources from all tree crops, annual crops and animal production (see also p. 1), then fill the rest of the columns*

Main Income sources *(ranked starting from the most important one)*	Overall production (for the whole year)	Home consumption (% or quantity)	Income (K sh) from sale	Do you buy any for your own consumption?
Farming income (including tree, crops, livestock)				
1.				
2.				
3.				
4.				
5.				
Off-farm Income				
(A: ________________) (B: ----------------------)	Amount: Monthly __________ yearly _____________ Monthly __________ yearly _________			
<u>Remittances</u> by family members leaving off farm	Amount: Monthly __________ yearly _____________			

other key income source Specify:		

15. Out of your income sources, which one is the **biggest**? Farm Off-farm
16. How **variable** is your income from farming from one year to the next?
    ____
    How variable is your income from off-farm activities from one year to the next?
    ____
17. What would you say are the **major challenges** limiting your farming these days?
    ____
    ____
    ____
18. Would your neighbors say you are a **good farmer** (don't be shy!)?
    ____
    ____
19. Do you sometimes **experiment / try out new things** on your own to improve your farming? No Yes
    If yes: what kinds of things have you already tried out in the past few years? In doing so, what was your purpose (idea)?
    ____
    ____
    ____
    ____

B. Farmer's Perception about climate change

1. Have you ever heard the words or expression **"climate change**"? No Yes
   If yes: From where / whom? (ex: radio/ TV, ag. officer,)____
   From what you heard, what is it that people mean / refer to when using these words? (Try to clarify any eventual confusion the farmer may have between CC and weather forecasting)
   ____
   ____
   ____
   ____
2. *Regardless what other people are saying***,** if you compare the way the weather is now and the way it was in the past, do you **personally** think **the weather has changed**? No Yes
   Since when has the weather changed according to you? (choose one of the 2) a. Specific date or number of years: ___________ b. no specific date, it has been changing continuously / gradually until now
   (brief spontaneous overall qualitative description of the main changes)
   ____
   ____
   ____
   ____
3. According to you, are there any **signs** that show the weather has indeed changed (such as behavior or disappearance / emergence of trees / wild animals / type of pests)? *NB: FOCUS on NATURE / Environment and DO NOT Get INTO YIELDS or PRODUCTIVITY here (it is being tackled in question B.8)*
   ____
   ____
   ____
   ____
   ____
   ____

4. Let's try and **compare** how the weather is now (2013-2014) and how it was ____ years ago (see B.2)

Instructions*: Explain how we will proceed.** *For each statement, ask the farmer if s/he agrees or disagrees (5 **classes**. 1=Agrees Strongly, 2=Agree more or less, 3=Disagree somewhat, 4=Disagree strongly. 99=Not Sure / Don't Know. In case of* ***disagreement*, ask farmer to formulate a alternative statement(s) s/he believes represents better the change that has taken place.*

(Some important statements may still need to be added)

Statements	Agree / Disagree	Alternative Statement formulated by farmer
Rainfall 1. Starting & finishing time of rainy season was much more predictable (reliable) in the past 2. I knew exactly when it was time for planting my crops in the past 3. Rains used to be erratic in the past 4. Rains were heavier in the past (like cats and dogs) 5. It could rain continuously for one full day or even more in the past 6. There were many days during the rainy season during which it would rain in the past 7. There were frequently floods and erosion as the result of heavy rains in the past 8. Nowadays, droughts during the rainy season have become more common 9. The dry season was longer in the past than today		
Temperature 1. It was warmer in January in the past 2. It was cooler in June -July in the past 3. Nowadays, you never know when it will be cold and when it will be hot. It can change from one day to the next 4. 5. 6. (On average, throughout the whole year, the weather was cooler in the past)		
Miscellaneous statements 1. Some crops that used to do well in the past like sorghum and millet can't be grown anymore nowadays 2. I was almost sure my crops would produce well in the past		

Lets' now turn to weather forecasting (short-term), and not to climate change over the long –term

5. Do you use (indigenous) (local) means of weather forecast nowadays? Never Not anymore Yes
   Do you consider such forecasts to be reliable /accurate / useful?
   ____
   ____
   If you used them in the past, but not anymore: why did you stop using them?
   ____
   ____
6. Do you use meteorological forecasting? Never Yes always Yes since _______ (date no of years)
   How different are they from the traditional forecasts?
   ____
   ____
   Do you consider these forecasts to be reliable /accurate / useful?
   ____
   ____
7. Which one of the 2 forecasts (traditional, meteorological) is the most accurate / reliable, and why?
   ____
   ____
   ____

A. Have the changes in the weather you described earlier been **affecting your farming** in one way or another (crops, livestock, trees, etc.)? No Yes ________
If yes, what concrete **effects** have they had?
____
____
____
____

Farmers' Adaptation Strategies to Climate Change

1. Have you done something in the way you farm to respond (adapt, counter) to the (long-term) changes in weather you just told us about? (Refer to answers obtained in question B7)? No Yes
2. If yes, what have you changed in your farming in response to the change in weather? (Give some time for the farmer to provide a **spontaneous answer** …)
   ____
   ____
   ____
   ____
   ____
   ____

*Now go through the following specific categories of possible changes: for every answer provided, **insist** to know whether s/he really strongly believes the change is related to long-term weather change*

A: Changes in **Tree management practices** (such as number and choice of trees planted, choice of varieties, dates of harvesting, intercropping, disease control, mulching, soil fertility management, input use, etc.)

____

____

B: Changes in **Crop management practices** (such as choice of crops planted, shifting crops between land types, choice of varieties, dates of planting, intercropping patterns, disease control, mulching, soil fertility management, input use, etc.)

____

C: Changes in **Livestock management practices** (such as choice of breeds, feeding strategies, stocking rates, ….)

____

D: Changes in **Land use and management practices** (such as farmed area, irrigation infrastructure, rainwater harvesting, other soil and water conservation measures, etc.)

____

E. Changes in **Livelihood strategies** (such as Mix of crops and livestock produce, combination of farm and off- farm activities, temporary or permanent migration of one of the family members, etc.)

____

3. How **difficult** has it been for you as a farmer to adapt to (long-term) weather change?

__Instructions__: Start by listing in the table below the main changes the farmer made as identified in Question C.2 above. Then, for each of them, ask the farmer if they were/ are difficult to implement, and why?

Main change introduced in response to weather change	Is / was this change difficult to implement? (from 0 = very easy to 3 =	Reasons for the difficulties , if any

	quite difficult)	

B. General / miscellaneous additional comments about the farm (free)

Ask the farmer if there is any information he would like to mention which is important to understand his farming or his strategies which we would have forgotten to ask about

Questions from the farmer to the researcher

Make sure you leave enough time at this moment, and before standing up and leaving for a free interchange by asking the farmer if s/he is interested in asking questions, whatever they may be, and strive to give as good, comprehensive, clear and honest answers as possible

Before leaving: thanks a lot! Any other information sharing

Visual timeline: History of the farm (try to keep it no longer than 30 – 45 mn)

Develop in a visual format (cards of various colors) shared with the farmer a time line from t0 (installation) until today (2014) based on key events related to the family cycle (wedding, death, birth & departure of children, inheritance, etc.), the farmed area, coffee production, crops or animals, and off-farm activities. For each event identified, ask the farmer to explain briefly its importance.
Start the timeline by describing situation for t0 and today, and then fill the intermediate dates

Were you already farming before establishing your own farm? (explain)

____

Land size	***Off-farm***	***Family***	*YEAR*	***Coffee***	***Crops***	***Animals***
			t0:			

			Today (2014)			

Observations and comments (anything useful to help understand the timeline and major events)

What is your vision (plans) about the future of your farm (next 5 – 10 years)? What does it depend on?

C. Current coffee & main crop management

to be filled during field tour taking into account o**ne full year**, mid-2013 to mid-2014

Varieties grown presently (no. of trees for each):

SL 28 ___ SL 27 __ SL 34 ______ Ruiru 11 ____ Batian ___

(after ticking first column, **to be filled by line**)

Main operations	Done this year? (Y/N)	Approx. date or period	labor use (days)	Type & Quantity of inputs used	Costs (K Sh)	Done other years?
Planting of new trees						

(which variety? __________						
Pruning						
Manure						
Fertilization (chemical) • Chemical 1 • Chemical 2 • Foliar						
Disease control						
Weeding						
Harvest						

1. Do you plant your coffee in the **shade**? No Yes. If no: why not?
   ____
   If yes: type of shade trees used: _______________ Reason: ____
2. Do you intercrop any other crops or trees in your coffer these days? No Yes
   If no: why not?
   ____
   ____
   If yes: what crops / trees?
   ____
   ____
   For what reason do you intercrop them?
   ____

3. Has your **management of coffee changed** over the past 10-15 years or so? No. Yes
   If yes, what do you do differently today compared to 10-15 years before?
   ____
   ____
   ____
   Specifically: have you changed **your input use**?
   ____
   ____
   Have you changed the varieties you plant?
   ____
   ____
   ____
   Why did you change your management practices?
   ____
   ____
4. **Trend** in **coffee production** over the past 30 years (if relevant / possible)
   Last harvest (Nov- Dec 2013) Production kg
   Compared to this last harvest, how has your production been changing?
   a. Decreased sharply moderately from a high of ___________ kg (year: _______) to ____ kg (today)
   b. Increased sharply moderately from of a low of ___________ kg (year: _______) to ____ kg (today)
   c. fluctuates markedly between ___________ kg and ________________ kg

d. more or less steady
Reason for above trend:
____
____

5. Do you **plan to make any changes** in your coffee production or management in the coming years (such as: Expansion / Reduction / Uprooting / Change of variety, Change in management practices, etc.)
____
____
____
____
____
____
(If changes envisioned) Why?
____
____
____
____

6. If the **price of coffee increases** compared to today, what ***changes*** are you likely to make in the management of your coffee?
____
____
____
____

7. And what if the **price of coffee decreases** compared to today, what would change?
____
____
____
____

The following questions focus on a maximum of 2 most important crops beside coffee, provided it is relevant.

8. **Current management** of your **<u>most important</u> food or feed crop**, that is __________________ (*pick from Q.A.2*)
For this crop specifically, please tell us if you apply:
a. manure? No Yes If Yes: how much? ____________________________ own? ______ Bought outside? ________
b. fertilizer? No Yes If Yes: what type ? _____________, _______ how much? _______________, ______________
c. pesticides? No Yes If Yes: which ones? how much? ____________________________
d. herbicides? No Yes If Yes: how much? ____________________________

9. **Current management** of your **<u>second most important</u> food** or **feed** crop, that is __________________

For this crop specifically, please tell us if you apply:
a. manure? No Yes If Yes: how much? ____________________________ own? ______ Bought outside? ________
b. fertilizer? No Yes If Yes: what type ? _____________, _______ how much? _______________, ______________
c. pesticides? No Yes If Yes: which ones? how much? ____________________________
d. herbicides? No Yes If Yes: how much? ____________________________

10. Types of inputs currently used on other "significant" crops last year (season) (**only indicate Yes or No**)

Crops	Fertilizer	Manure	Pesticide	Herbicide
Tree crops (other than coffee) (which ones? ____________, _____________				
Vegetables (which ones? _________________)				
Root crops (potato, arrowroot)				
Napier grass				

11. Use / Recycling of organic material from the farm:

(1) M**anure** Produced on the farm? Yes No Mixed with leaves or weeds? _________________

Do you produce enough manure for all your needs on your farm? No Yes

If not, is it easy for you to find manure nearby?

____
____
____
____

(2) **Compost** Produced on the farm? Yes No Since when? _______________

Why did you start composting?

____

Sources of compost material

____
____
____
____

(3) **Mulching** Practiced on the farm? Yes No Since when? ______________

Why did you start mulching?

____

Source of mulching material:

____
____

Appendix 9 Data Collection Instrument: Food crop farmers' household questionnaire

Date of interview ____/____/____, HH Identification Number (code) _______**Name**: _______________________________________County: **Muranga**, sub county________________, Location ______________________, Sub Location ________________________ Altitude ________________, GPS coordinates ________________________________ Farming system ___________________________________

(Upon arrival) Introduction of research objectives & research team + agenda

Quick tour of the farm with the farmer (max. 45 mn incl. questions)

A. General information about the household and the farm

1. Years since establishment ____________ (as autonomous farmer)
   Farm Size (acres) a. own land _________ b. rented land _________ c: Total ______
   how many plots? ________________ (based on field tour prior)
2. What are your main productions (trees, crops, animals): 1: ______________ 2: _________________ 3: __________________
   (in order of importance) 4: _________________ 5: _________________, 6: __________________ 7: ___________________
3. What animals do you raise? Cows ____ Calves ______ Goats____ Sheep_____
   Pigs ____Chicken ______ Others _______
4. **Family & family labour** (***start*** by listing those who work on the farm, ***then list*** any other family members
5. Marital status of HHH 1=Married, 2=Single, 3=Widowed, 4=Divorced, 5=Separated, Gender: ____________
6. How many grown-up children do you have that live independently from you today? ___________

Name of HH Member	Status	Sex	Age	Education (years)	Lives in the homestead	time spent farming			Off-farm job? yes no what is it
						Full time	Part-time	Not involved	
6.	HHH								
7.									
8.									
9.									
10.									
11.									

7. Do you hire temporary labour to help you with your farming? No Yes
   If yes: for which activities / crops?
   ____

_
how often? ____

8. Are you a **member of a cooperative or any other organization related to farming**? 0. No 1. Yes
If yes, which one(s)? ,____?
Position you occupy? __________________________________
9. Access to **irrigation**? No Yes if yes, the type____
10. Distance to most common **input market** in KMs ______ time _________ min
(access: walking public transport own transport)
Distance to most common **produce market** in KMs? _______ time _______ min
(access: walking public transport own transp.)

11. Do you have **access to credit** for your farming when you require it? No Yes
Do you use it every year? _________________________
12. Do you have **access to extension / advisory services**? No Yes,

If yes, what types of advice / services? ____
Who provides it to you?
____
How important / valuable is this advice to you?
____
_

13. History of the farm (See page 9)

14. Production & related **INCOME CONTRIBUTION** for Year **2013-2014** (Mid-2013 to Mid-2014)

<u>Instructions</u>: Star first by selecting up to a maximum of 5 main income sources from all tree crops, annual crops and animal production (see also p. 1), then fill the rest of the columns

Main Income sources *(ranked starting from the most important one)*	**Overall production (for the whole year)**	**Home consumption (% or quantity)**	**Income (K sh) from sale**	Do you buy any for your own consumption?
Farming income (including tree, crops, livestock)				
1.				
2.				
3.				
4.				
5. **6.**				
Off-farm Income				
(A: ______________________	Amount: Monthly _______________ yearly ____________________			

___) (B: -----------------------)	Monthly _______________ yearly _____________	
<u>Remittances</u> by family members leaving off farm	Amount: Monthly _______________ yearly ____________________	
<u>other key income source</u> Specify**:**		

15. Out of your income sources, which one is the **biggest**? Farm Off-farm

16. How **variable** is your income from farming from one year to the next? ____________________
    How variable is your income from off-farm activities from one year to the next? _______________

17. Do you sometimes **experiment / try out new things** on your own to improve your farming? No Yes
    If yes: what kinds of things have you already tried out in the past few years? In doing so, what was your purpose (idea)?
    ____
    ____
    ____
    ____
    ____
    ____
    _____

A. Farmer's Perception about climate change

1. Have you ever heard the words or expression **"climate change**"? No Yes
   If yes: From where / whom? (ex: radio/ TV, ag. officer,)____
   From what you heard, what is it that people mean / refer to when using these words? (Try to clarify any eventual confusion the farmer may have between CC and weather forecasting)
   ____
   ____
   ____
   ____
   ____
   ____

2. *Regardless what other people are saying***,** if you compare the way the weather is now and the way it was in the past, do you **personally** think **the weather has changed**? No Yes
   Since when has the weather changed according to you? (choose one of the 2) a. Specific date or number of years: ___________ b. no specific date, it has been changing continuously / gradually until now
   (brief spontaneous overall qualitative description of the main changes)
   ____

____
____
____
____
____

3. According to you, are there any **signs** that show the weather has indeed changed (such as behavior or disappearance / emergence of trees / wild animals / type of pests)? *NB: FOCUS on NATURE / Environment and DO NOT Get INTO YIELDS or PRODUCTIVITY here (it is being tackled in question B.8)*

____
____
____
____
____
____
____
____

4. Let's try and **compare** how the weather is now (2013-2014) and how it was ____ years ago (see B.2)

*__Instructions__: **Explain how we will proceed.** For each statement, ask the farmer if s/he agrees or disagrees (5 __classes__. 1=Agrees Strongly, 2=Agree more or less, 3=Disagree somewhat, 4=Disagree strongly. 99=Not Sure / Don't Know. In case of **disagreement**, ask farmer to formulate a alternative statement(s) s/he believes represents better the change that has taken place.*

(Some important statements may still need to be added)

Statements	Agree / Disagree	Alternative Statement formulated by farmer
__Rainfall__ 5. Starting & finishing time of rainy season was much more predictable (reliable) in the past 6. I knew exactly when it was time for planting my crops in the past 7. Rains used to be erratic in the past 8. Rains were heavier in the past (like cats and dogs) 9. It could rain continuously for one full day or even more in the past 10. There were many days during the rainy season during which it would rain in the past 11. There were frequently floods and erosion as the result of heavy rains in the past 12. Nowadays, droughts during the rainy season have become more common 13. The dry season was longer in the past than today		
__Temperature__ 7. It was warmer in January in the past		

8. It was cooler in June -July in the past 9. Nowadays, you never know when it will be cold and when it will be hot. It can change from one day to the next 10. (On average, throughout the whole year, the weather was cooler in the past)		
Miscel. statements 3. Some crops that used to do well in the past like sorghum and millet can't be grown anymore nowadays 4. I was almost sure my crops would produce well in the past		

Lets' now turn to weather forecasting (short-term), and not to climate change over the long –term

14. Do you use (indigenous) (local) means of weather forecast nowadays? Never Not anymore Yes
    Do you consider such forecasts to be reliable /accurate / useful?
    ____
    ____
    If you used them in the past, but not anymore: why did you stop using them?
    ____
    ____
15. Do you use meteorological forecasting? Never Yes always Yes since _______ (date no of years)
    How different are they from the traditional forecasts?
    ____
    ____
    Do you consider these forecasts to be reliable /accurate / useful?
    ____
    ____
16. Which one of the 2 forecasts (traditional, meteorological) is the most accurate / reliable, and why?
    ____
    ____
    ____
    ____
17. Have the changes in the weather you described earlier been **affecting your farming** in one way or another (crops, livestock, trees, etc.)? No Yes ________
    If yes, what concrete **effects** have they had?

B. Farmers' Adaptation Strategies to Climate Change

1. Have you done something in the way you farm to respond (adapt, counter) to the (long-term) changes in weather you just told us about? (Refer to answers obtained in question B7)? No Yes
2. If yes, what have you changed in your farming in response to the change in weather? (Give some time for the farmer to provide a **spontaneous answer** …)

*Now go through the following specific categories of possible changes: for every answer provided, **insist** to know whether s/he really strongly believes the change is related to long-term weather change*

A: Changes in **Tree management practices** (such as number and choice of trees planted, choice of varieties, dates of harvesting, intercropping, disease control, mulching, soil fertility management, input use, etc.)

B: Changes in **Crop management practices** (such as choice of crops planted, shifting crops between land types, choice of varieties, dates of planting, intercropping patterns, disease control, mulching, soil fertility management, input use, etc.)

C: Changes in **Livestock management practices** (such as choice of breeds, feeding strategies, stocking rates, ….)

D: Changes in **Land use and management practices** (such as farmed area, irrigation infrastructure, rainwater harvesting, other soil and water conservation measures, etc.)

E. Changes in **Livelihood strategies** (such as Mix of crops and livestock produce, combination of farm and off- farm activities, temporary or permanent migration of one of the family members, etc.)

____
____
____
____
____
____

3. How **difficult** has it been for you as a farmer to adapt to (long-term) weather change?

<u>Instructions</u>: Start by listing in the table below the main changes the farmer made as identified in Question C.2 above. Then, for each of them, ask the farmer if they were/ are difficult to implement, and why?

Main change introduced in response to weather change	Is / was this change difficult to implement? (from 0 = very easy to 3 = quite difficult)	Reasons for the difficulties , if any

C. General / miscellaneous additional comments about the farm (free)

Ask the farmer if there is any information he would like to mention which is important to understand his farming or his strategies which we would have forgotten to ask about

Questions from the farmer to the researcher

Make sure you leave enough time at this moment, and before standing up and leaving for a free interchange by asking the farmer if s/he is interested in asking questions, whatever they may be, and strive to give as good, comprehensive, clear and honest answers as possible

Before leaving: thanks a lot! Any other information sharing

Visual timeline: History of the farm (try to keep it no longer than 30 – 45 mn)

Develop in a visual format (cards of various colors) shared with the farmer a time line from t0 (installation) until today (2014) based on key events related to the family cycle (wedding, death, birth & departure of children, inheritance, etc.), the farmed

area, coffee production, crops or animals, and off-farm activities. For each event identified, ask the farmer to explain briefly its importance.
Start the timeline by describing situation for t0 and today, and then fill the intermediate dates

Were you already farming before establishing your own farm? (explain)
____

Land size	***Off-farm***	***Family***	*YEAR*	***Coffee***	***Crops***	***Animals***
			t0:			
			↓			
			Today (2014)			

Observations and comments (anything useful to help understand the timeline and major events)
____
____
____

What is your vision (plans) about the future of your farm (next 5 – 10 years)? What does it depend on?
____
____

4. Do you practice intercrop these days? No Yes
   If no: why not?
   ____
   ____
   If yes: what crops / trees?
   ____
   ____
   For what reason do you intercrop them?
   ____

5. Did you ever have coffee in your farm at any time in the past? If yes when___________________________________

   If you had in the past but not today, what is the reason for the disappear of coffee from your farm?____
   ____
   ____
   ____

   Do you **plan to bring coffee back**?____
   ________________________,
   how?____
   ____
   ____
   ____________________________________,
   why?____
   ____

The following questions focus on a maximum of 2 most important crops beside coffee, provided it is relevant.

6. **Current management** of your **<u>most important</u> food or feed crop**, that is _________________ (*pick from Q.A.2*)

For this crop specifically, please tell us if you apply:
a. manure? No Yes If Yes: how much? ___________________________ own? ______ Bought outside? ________
b. fertilizer? No Yes If Yes: what type ? _____________, _______ how much? _______________, _____________
c. pesticides? No Yes If Yes: which ones? how much? ___________________________
d. herbicides? No Yes If Yes: how much? ___________________________

7. **Current management** of your **<u>second most important</u> food** or **feed** crop, that is _________________

For this crop specifically, please tell us if you apply:
a. manure? No Yes If Yes: how much? ___________________________ own? ______ Bought outside? ________
b. fertilizer? No Yes If Yes: what type ? _____________, _______ how much? _______________, _____________
c. pesticides? No Yes If Yes: which ones? how much? ___________________________
d. herbicides? No Yes If Yes: how much? ___________________________

8. Types of inputs currently used on other “significant” crops last year (season) (**only indicate Yes or No**)

Crops	Fertilizer	Manure	Pesticide	Herbicide
Tree crops (other than coffee) (which ones? ____________, _____________				
Vegetables (which ones? _________________)				
Root crops (potato, arrowroot)				
Napier grass				

9. Use / Recycling of organic material from the farm:
   (1) M**anure** Produced on the farm? Yes No Mixed with leaves or weeds? _________________
   Do you produce enough manure for all your needs on your farm? No Yes
   If not, is it easy for you to find manure nearby?
   ____
   ____
   ____
   ____

   (2) **Compost** Produced on the farm? Yes No Since when? _______________
   Why did you start composting?
   ____
   ____
   Sources of compost material
   ____
   ____
   ____
   ____

   (3) **Mulching** Practiced on the farm? Yes No Since when? ______________
   Why did you start mulching?
   ____
   ____
   Source of mulching material:
   ____
   ____

Appendix 10 Data Collection Instrument: Stakeholders' Interview Checklist

Research Topic: Impact of Climate Change on the Agro-Ecological Innovation of Coffee Agroforestry Systems in Murang'a, Kenya

Survey Checklist *(Coffee cooperative)*

Kinfe Asayehegn, GEBREEYESUS, Latest Version July 17/2015

1. General information

1.1. Introduce the cooperative when, why, and how it was established? The key missions, major roles and structural operations of the organization? What departments do you have?

1.2. Number of coffee societies, date and year of installations, number of newly/recently installed, number of dormant/closed societies?

1.3. Number of dairy cooperatives, date and year of installations, number of newly/recently installed, number of dormant/closed dairy cooperatives?

1.4. Please briefly tell me the history of coffee in Kenya in general and in Murang'a in particular.

1.5. What differences in terms of benefits (income), productivity(product per unit area), product prices and market acceptability, cup quality, input costs (fertilizer, pesticide), labor costs (costs for managing and harvesting) have you observed between the old varieties of SL and the new varieties of Ruiru 11 and Batian?

2. Modes of interaction with other actors

2.1. Would you tell me with whom you have been working on coffee and why? *Internal and external actors' linkage, who initiated the connection*? (farmers, communities, government at local or national, local NGOs, private sector, research institutes/universities, international NGOs, CBOs), *additional information in the Table*

Agency	Internal	External	Vertical	Horizontal
Government				
NGOs local				
NGO international				
Private sector				
Research				
University				
CBOs				
Farmers				

2.2. What are the roles of each actor in the coffee development? Can you tell me the sources of the fund, leadership, management? Who provides new strategies; experiences and new opportunities?

2.3. How do you decide what type of support to bring to farmers? Do farmers request for support? Or you provide them what you have at hand? Who sets the agenda while involving other actors

2.4. To what extent do you involve farmers in technology development, extension and dissemination process? If yes, who initiates the agenda of collaboration? How and why? What were the roles of farmers in the process?

3. Impact pathway

3.1. Do you think the new varieties recently developed are massively disseminated? Do farmers have easy access to the seedlings? If not, what are their reasons? Do you think farmers have sufficiently adopted the new varieties? If not, what do you think the reasons for low adoption?

3.2. What is your major contribution to the development of the sector? *in terms of technology production, new modes of thinking, learning process, learning outputs, policy devise, structure, institutional development, entrepreneurial change and new ways of doing things*?

3.3. What the results of the coffee variety development you dealt in terms of *income generation, capital formation, food security, resiliency, technologies produced/ adopted, and policies execution?*

4. Specialization, diversification and transition

4.1. As expert/stakeholder in the coffee sector of the study area, have you observed any change in production system, livelihood activities of the community (any change to technical intensification of coffee, any change from coffee and crop production to livestock and other cash crops production, from farming to nonfarm)? Why do you think such changes have been taking place? Can you tell us the brief story for the last 10-20 years?

5. Determinants, challenges and constraints

5.1. What do you think are the major challenges for the coffee sector development of the area? Do you think the attractions from other sectors such as livestock and nonfarm business as challenges to the coffee sector development? If so how and why? *Seeks general challenges*

Questions for Coffee Research Foundation (CRI)

6. General Introduction

6.1.Please briefly present explanation of your organization on when, why, and how it was established? What are/were the key missions, major roles and structural operations? What programs, projects, sections, and departments do you have? What kind of results have you obtained so far? Who within/outside your organization also works on this theme?

6.2. Please briefly tell me the history of coffee and coffee varieties in Kenya in general and in Murang'a in particular. Do you think the new coffee varieties have solved the problem of the old varieties had? Are there other problems with the new variety today? Do you need to develop new varieties still? Why? What do you need/problems to improve for the new variety?

6.3. What differences in terms of benefits (income), productivity(product per unit area), product prices and market acceptability, cup quality, input costs (fertilizer, pesticide), labor costs (costs for managing and harvesting) have you observed between the old varieties of SL and the new varieties of Ruiru 11 and Batian? *A question for socio-economist*

6.4.What makes farmers, traders, consumers, interested in the new varieties vs. the old SL? If there are some differences in interest among the producers, traders and consumers on the different varieties, what are the differences in interest?

7. Modes of interaction with other actors

7.1. Would you tell me with whom you have been working on coffee and why? *Internal and external actors' linkage, who initiated the connection*? (farmers, communities, government at local or national, local NGOs, private sector, research institutes/universities, international NGOs, CBOs), *sketch a flow chart/table*

Agency	Internal	External	Vertical	Horizontal
Government				
NGOs local				
NGO international				
Private sector				
Research				
University				
CBOs				
Farmers				

7.2.What is/are the role/s of each actor in the coffee variety development? Can you tell me the sources of the fund, leadership, management? Who provides new strategies; experiences and new opportunities?

7.3.Who sets the agenda while involving other actors (*take an example of product/technology/ network*)? How and why? How is the line of interaction/who supplies, demands and contributes? *More explanation during interview*

7.4. To what extent do you involve farmers in technology development, extension and dissemination process? If yes, who initiates the agenda of collaboration? How and why? What were the roles of farmers in the process? Do you request farmers to evaluate the technology and seek feedbacks? Why? How?

8. Specialization, diversification and transition

8.1. As expert/stakeholder in the coffee sector of the study area, have you observed any change in production system, livelihood activities of the community (any change to technical intensification of coffee, any change from coffee and crop production to livestock and other cash crops production, from farming to nonfarm)? Why do you think such changes have been taking place? Can you tell us the brief story for the last 10-20 years?

8.2. Do you encounter any challenge while developing, disseminating, promoting and adaptation of coffee technologies such as the new varieties? If yes, what challenges particularly? Why?

To make it specific, what are the difficulties that you encountered from your working environment during the course of the executions of your work? Constraints coming from the structure, from the other stakeholders/ actors in general? Other constraints from internal/ external of the system/organization? Weather related challenges? *Challenges specific to the variety*

8.3. Have you done something to solve the challenges/constraints you faced? What have you done specifically, to solve which challenge/constraint? How?

8.4. What do you think are the major challenges for the coffee sector development of the area? Do you think the attractions from other sectors such as livestock and nonfarm business as challenges to the coffee sector development? If so how and why?

10. Capacity to innovate

10.1. How do you learn about new ways of doing things, grass root problems, applicability and adoptability/adaptability of your technologies/products/, who is doing what?

10.2. How do you inform/make know other actors about your activities, programs, products?

10.3. How do you insure farmers and other stakeholders participate in creating new things, adopt and adapt technologies?

10.4. What type of capacity building and training do you provide to farmers and other stakeholders on the coffee variety? How do you set the agenda of capacity building? Who participates in setting the agenda?

Other Actors

11. General information

11.1. Please briefly introduce your organization on when, why, and how it was established? What are/were the key missions, major roles and structural operations of the organization? What programs, projects, sections, and departments do you have in the organization?

11.2. What are your main objectives and activities on the coffee sector development? Since how long have you been working on this theme?

11.3. Please briefly tell me the history of coffee and coffee varieties in Kenya in general and in Murang'a in particular.

11.4. What differences in terms of benefits (income), productivity(product per unit area), product prices and market acceptability, cup quality, input costs (fertilizer, pesticide), labor costs (costs for managing and harvesting) have you observed between the old varieties of SL and the new varieties of Ruiru 11 and Batian? *A Table will be used for presenting answers in details*

12.Modes of interaction with other actors

12.1. Would you tell me with whom you have been working on coffee and why? *Internal and external actors' linkage, who initiated the connection*? (farmers, communities, government at local or national, local NGOs, private sector, research institutes/universities, international NGOs, CBOs), *additional information in the Table*

Agency	Internal	External	Vertical	Horizontal
Government				
NGOs local				
NGO international				
Private sector				
Research				
University				
CBOs				
Farmers				

12.2. What is/are the role/s of each actor in the coffee variety development? Can you tell me the sources of the fund, leadership, management? Who provides new strategies; experiences and new opportunities?

12.3. How do you decide what type of support to bring to farmers? Do farmers request for support? Or you provide them what you have at hand? *More explanation during interview*

12.4. To what extent do you involve farmers in technology development, extension and dissemination process? If yes, who initiates the agenda of collaboration? How and why? What were the roles of farmers in the process? Do you request farmers to evaluate the technology and seek feedbacks? Why? How?

13. Determinants, challenges and constraints

13.1. Have you done something to solve the challenges/constraints you faced? What have you done specifically, to solve which challenge/constraint? How?

13.2. What do you think are the major challenges for the coffee sector development of the area? Do you think the attractions from other sectors such as livestock and nonfarm business as challenges to the coffee sector development? If so how and why? *Seeks general challenges*

13.3. Capacity to innovate

13.4. How do you learn about new ways of doing things, grass root problems, applicability and adoptability/adaptability of your technologies/products/, who is doing what?

13.5. How do you inform/make know other actors about your activities, programs, products?

13.6. How do you insure farmers and other stakeholders participate in creating new things, adopt and adapt technologies?

THANK YOU FOR YOUR TIME AND DETERMINATION